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Editor

Encyclopedia of Science Education

Springer Reference

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With 88 Figures and 32 Tables

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Preface

This is the first English language Encyclopedia of Science Education to be published and, as far as I have been able to determine, the first Encyclopedia of Science Education in any language.

But "being the first" does not mean "this is needed." So why an *Encyclopedia* of Science Education? This was literally my immediate reaction when Harmen van Paradijs, then Springer's science education editor, first asked me some years ago if I would create and edit an Encyclopedia of Science Education for Springer. After all, quite comprehensive handbooks of Science Education had been a common feature of our research world for two decades: The USA-based National Association for Research in Science Teaching (NARST) initiated the first (in 1993, edited by Dorothy Gabel). At the time Harmen spoke with me, there were two current well-known handbooks, one endorsed by NARST (edited by Sandra Abell and Norman Lederman) and the other published by Kluwer (now Springer, edited by Barry Fraser and Kenneth Tobin), and the second (and current) editions of each of these were both already well underway. Two of the eventual seven volumes in the regionally focused series of handbooks of Science Education research published by Sense had by then been completed. And the journal *Studies in Science Education*, a journal primarily devoted to reviews of science education research, was then in its 45th year. Clearly, an encyclopedia was not justified if it was to be just another form of handbook.

Why *This* Encyclopedia of Science Education?

In general terms, an encyclopedia ought to be different from a handbook, given both the format of large numbers of separate contributions ordered alphabetically (rather than single-/joint-authored major reviews of broad topics) and the ways this differing format invites different approaches to synthesizing research findings and future directions.

I spent some time considering the question of why *this* Encyclopedia of Science Education before deciding I had answers acceptable to me and so agreed to Harmen's invitation. Arriving at my answers involved exploring two things: whether I believed science education warranted an encyclopedia and how such a publication could be sufficiently different to anything currently in existence so as to attract me to accepting the major commitment that the creation and editing would involve.

Commonly, encyclopedias are defined as something of the form of "a comprehensive reference work – book or set of books – containing extensive information on all branches of knowledge or on one particular branch of knowledge, usually arranged alphabetically." The issue as to whether or not science education deserves such a publication is, as I see it, easily settled. As an English language label to describe an area of research and teaching, "Science Education" essentially emerged for the first time in the very early 1960s. This was in particular response to the proliferation of a range of evaluation types of studies of the then new and large-scale US science curriculum projects. It was at this time, for example, that the first named Professors of Science Education were appointed (first in USA, then in Australia). Thus, the discipline is, by this name, only about half a century old. Yet, science education has developed rapidly and remarkably. Fensham's 2004 book *Defining an Identity: Science Education as a Field of Research* (Kluwer) alone would make a convincing case in the powerful presentation of data and analyses that he gives to support the proposition that science education does indeed have the status of a distinct "field of research." Many other observations are also convincing about this status of science education; for example, there are now at least eight specifically science education journals included in the highly selective Thomson Reuters (formerly ISI) Web of Knowledge database and several others such as *Science Communication* and *Science and Society*, in which science education researchers are among those who publish. This is considerably more than for any other specialist school curriculum area.

So I became comfortable with the notion that science education as a research field warranted an encyclopedia. And then, I saw that something of substantial potential worth and quite different to what currently existed could be attempted – in short, I would attempt to have research authors and research traditions from beyond the dominating anglophone/English language research world represented in the encyclopedia. That is, I would take "comprehensive," perhaps the central characteristic of an encyclopedia, to include recruiting authors from around the globe and attempting to identify and include relevant non-English language constructs and literatures and perspectives – while being clear at all times that this was to be a solely English language publication.

Some researchers have previously pointed to the sharp contrast between the nature of causality that science itself seeks and the nature of causality that it is feasible to seek in science education. In simple terms, causality in science seeks to be singular and absolute, while causality in science education is necessarily multiple and relative (e.g., both *context* – including the content that is the focus of the teaching/learning/curriculum/assessment – and *time* are very often determining causal variables in our research even though they are often treated as issues that can somehow be ignored or "controlled"). Too often, science education research and practice seeks some form of absolute and constant causality that cannot be attained.

One central aspect of the multiple causality that is inherent to [science] education research is that some fundamental issues are conceptualised quite differently in different sociohistorical-cultural contexts. That is, for some issues, the beginning points of even thinking about how to investigate aspects of causality are in sociohistorical-cultural contexts different to, for example, my own. A quite widely recognised example of this, an example that is also frequently only understood at the most superficial level in the anglophone world, is the way in which the range of issues the anglophone world gathers together under the broad concern of "how do we decide what content to teach and how to teach this?" are conceptualised in parts of continental Europe (see the entries *Bildung* and *Didaktik* in this encyclopedia). The issue I saw as "being of substantial potential worth and quite different to what currently existed" that I have attempted to include in this encyclopedia is that of alternative ways of conceptualising central issues in science education that, for those of us who are monolingual, are currently unavailable.

The Processes of Generating the [Changing] List of Entries

I first began by recruiting a number of outstanding science education scholars to work with me as an Editorial Board, with each of them having particular expertise in one of a range of broad areas (Assessment, Curriculum, Nature of Science, Teaching, Learning, etc.). All are from the anglophone world of science education research – I had a further strategy to broaden the range of entries and authors (see below).

The Editorial Board had one face-to-face meeting immediately prior to the 2010 conference of the National Association for Research in Science Teaching. This was supported by Springer with costs and with both secretarial and intellectual support. Prior to that meeting, I generated a first draft of possible entries by (a) using the indexes of the two Handbooks of Science Education that were in print then and (b) working through the complete contents to that time of the review journal *Studies in Science Education*. We (the Editorial Board) then spent most of our one meeting working through this list, revising and adding and deleting entries and sometimes suggesting authors. We also agreed on the ways we would divide up the work involved in seeking authors and editing entries. Although it was never intended that the final publication would involve separate sections, the allocation of responsibilities by section was to enable the best use of the outstanding expertise involved on the Editorial Board.

Entries relating to Assessment and Evaluation were the responsibility of Audrey Champagne, Curriculum – Robin Millar, Intersections with Other Substantive Areas – Justin Dillon (resigned March 2011; I took over these entries), Learning – the late Phil Scott and me (because of the extremely large number of entries here, Phil and I intended to share responsibility; on Phil's tragically early death in July 2011, I took over all entries in this area), Nature of Science – Rick Duschl; Science Education in Out-of-School Contexts – Léonie Rennie, Socio-Cultural Dimensions of Science Education – Bill Cobern, Teacher Education/Teacher Development – John Loughran, Teaching – John Wallace, Technology-Enhanced Learning – Doris Jorde, replaced by Jim Slotta in January 2012.

Over the next several months, the list of proposed entries was further developed and expanded to include notional length (either short [up to ~1,000 words], medium [~1,200–1,500], long [~1,500–4,000] or essay [~5,000]) and an outline of a sentence or two about the intent of the entry. These two added features were to enable invited authors to be more informed about the task. The list of entries has remained a changing phenomenon right to the point of production. I am very grateful to all members of the Editorial Board for the wholehearted and insightful ways they engaged with this uncertain process of developing what the encyclopedia would contain and for which we were continuously working out for ourselves how to approach this central task.

Our approaches to expanding the entries and authors to embrace ideas and people from beyond the anglophone world involved my creation of an Advisory Board of science education academics. These were scholars who knew well the English language literature in their specialty, who knew well the literature in their first language, and who knew the ways research was conceptualised in their own culture. The invitations I sent out early in 2011 explained the embracing of ideas and people beyond the anglophone world I wanted to include in the encyclopedia. I included the list of entries as it then stood and described what I was inviting them to undertake as considering the list of proposed encyclopedia entries with the task of identifying

(i) Potential authors from beyond anglophone contexts for entries proposed by the Editorial Board.
(ii) Issues (potential entries) that do not appear in this list of entries generated by the Editorial Board that are of importance to the traditions/literatures with which the Advisory Board member is familiar.
(iii) Entries that are on the list for which the perspectives of the Advisory Board member's tradition/literature are different from the perspectives of the anglophone traditions and literatures and different in significant ways – that is, in ways whose elaboration will help inform and enhance the English language/anglophone perspectives.

Those who agreed to be involved and their countries are Jens Dolin (Denmark), Reinders Duit (Germany), Mansoor Niaz (Venezuela), Masakata Ogawa (Japan), Roser Pintó (Spain), Marissa Rollnick (South Africa), Jinwoon Song (Republic of Korea), Fatih Taşar (Turkey), Andrée Tiberghien (France), Benny Yung (Hong Kong SAR, People's Republic of China).

As with the Editorial Board, I am extremely grateful for the considerable time and expertise that these members of the Advisory Board have given to the production of the encyclopedia.

The Nature of the Final Entries

In this first edition of the Encyclopedia of Science Education, there are 383 substantive entries and another 1793 entries that are only cross-references (e.g., there is an entry *Accommodation in Piagetian Theory* that is only a cross-reference – see "Piagetian Theory" – because Accommodation as advanced by Piaget is discussed in detail in *Piagetian Theory*). These entries have involved 353 different authors, and the authors plus Advisory Board members plus Editorial Board members have come from 36 different countries.

Some entries are of considerable length and cover all of a major field (e.g., *Piagetian Theory*), and others, by the specific circumstance of related entries, are quite brief (e.g., *Meaningful learning* is only about 140 words because this construct and the way it has been conceptualised in science education is considered at some length in the entry *Ausubelian Theory of Learning*; therefore, *Meaningful learning* is cross-referenced to *Ausubelian Theory of Learning* rather than all relevant material being repeated in each entry).

The intended audience for this encyclopedia is, put simply, beginning researchers – either research students (and so "beginning" in the conventional sense) or existing researchers who are exploring an area beyond their current expertise (and so "beginning" only in terms of the focus of the entry they seek). Clearly then, the expectation of all involved in the production of these volumes is that readers will always be sampling the specific parts that reflect their needs at the time and following cross-references as appropriate to further explore their immediate needs. It is very hard to imagine this work being read in the sequential manner of conventional books.

Acknowledgements

It is appropriate for me to repeat here what is written above – both the Editorial Board and the Advisory Board have given a very great deal by way of commitment and expertise to the production of this encyclopedia.

While all members of both Boards have been absolutely central to the development of this encyclopedia, I have used two members of the Editorial Board more than all others as sources of advice and as sounding boards for my thinking – my two Australian friends and colleagues Léonie Rennie and John Loughran. I am especially grateful to them for their unfailing and immediate willingness to help in a variety of ways and with a huge range of thoughts and concerns. John also has my sincere thanks for the ways he has happily and very helpfully responded to my innumerable verbal queries delivered (usually) very early in the morning as he sat in his Dean's office trying to do uninterrupted work only to have me rush in and ask about my latest encyclopedia concern.

I also wish to specifically acknowledge the contributions of the late Phil Scott. Phil and I had been colleagues and friends since his first year at the University of Leeds (which coincided with a period of sabbatical leave I spent at Leeds). Initially, as he and I worked together on the development of entries related to Learning, I could not have asked for a more expert and congenial colleague – just as Phil was, unfailingly, with all. Then, after his sudden death, I invited those authors he had suggested in ways that made it clear that the suggestion of the author was Phil's, not mine. The response was almost

ubiquitously remarkable. It was not that people said "yes" (as they almost always did); it was that they were genuinely touched by it being Phil's idea to involve them. The warmth felt towards this wonderful man shone through over and over again.

Melbourne Richard Gunstone
Jan 2014

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[1] Resigned March 2011

[2] Resigned January 2012

[3] Died suddenly July 2011

[4] From February 2012

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Access of Historically Excluded Groups to Tertiary STEM Education

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Keywords

Academic support or development programs; Access; Bridging; Epistemological access; Extended curriculum; Higher education access; Remedial

Access programmes

In most countries access to tertiary STEM (science, technology, engineering, and mathematics) study is restricted to those who attend schools that offer prerequisite preparation, predominantly in mathematics, the main gatekeeping requirement to STEM study in almost all contexts around the world. This restriction leads to either a shortage or a lack of diversity among STEM students, as these schools usually serve the middle and upper socioeconomic groups in any population. In developing countries this pattern is exaggerated even further to the extent that students of first-year undergraduate science classes are often drawn from just a few schools in the whole country. For example, in 1999/2000, 65–75 % of students admitted to two of Ghana's most prestigious universities were drawn from only 50 out of the 500 plus secondary schools in that country. To address this problem, many countries institute special programs known as access programs to increase the number and diversity of students in these programs. This is an attempt to break the vicious circle in science education, illustrated in Fig. 1 below (Rollnick 2010, p. 13). Access programs generally intervene in the cycle both by providing greater numbers of school leavers into the system and by improving throughput at university.

Access programs serve different clientele depending on the country context. In developed countries access program students would most likely be mature adults making late decisions to enter tertiary education or ethnic minorities. Both groups may have been excluded from mathematics and science in secondary school. In developing countries those students able to enter higher education in science tend to come from a few elite schools, while the more able students from the majority of schools are not able to gain access.

Access programs differ in their structures but in most cases increase the duration of the undergraduate program. Figure 2 below summarizes the most common models assuming a 3-year undergraduate degree (Rollnick 2010, p. 17). Four-year degrees would be similar with an additional year.

The first two models are the most common and the least transformative in their orientation but can be further classified according to whether the

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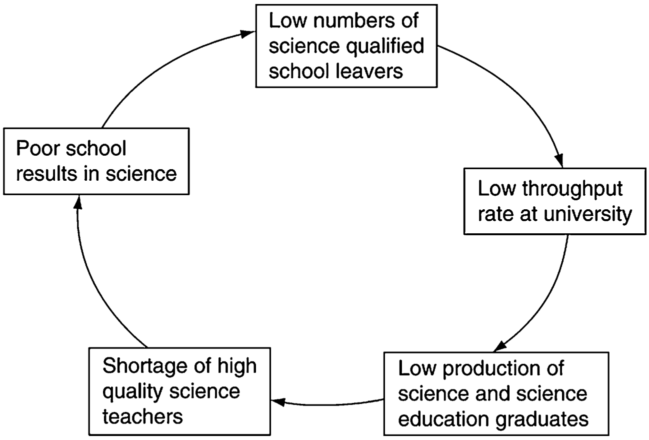


Access of Historically Excluded Groups to Tertiary STEM Education, Fig. 1 The vicious cycle of science performance

Access of Historically Excluded Groups to Tertiary STEM Education, Fig. 2 Schematic description of different models

Type of Model	Year 0	Year 1	Year 2	Year 3
Normal course and extra tutorial/enrichment model	Non Existent	Normal Degree Structure		
1+3	Foundation year	Normal Degree Structure		
2+2	Two year Access programme		Senior years of main degree	
Complete restructuring	Year 1	Year 2	Year 3	Year 4

institution directly offers the program or whether it is outsourced. A study of various initiatives internationally led to the characterization shown in Fig. 3 (Rollnick 2010, p. 46).

"Inreach" in Fig. 3 refers to programs aimed at getting students from underrepresented communities into programs such as summer schools and adult access programs. These may be offered by the university itself or outsourced. Flexible programs are described as those that involve adjustments to the HE delivery, structure, or administration and include cooperation between different types of institutions, open learning, and part-time provision. Systemic initiatives are large scale, commonly at the school level, aiming to improve access by improving the school system as a whole.

Within these categories, the type of support that is provided is categorized as follows:

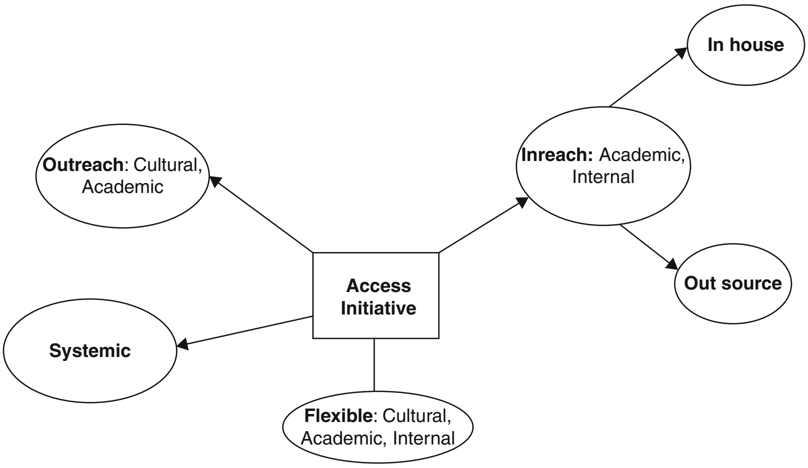
- Academic: Support aimed directly at assistance or offering of relevant content
- Cultural: Support aimed at providing broader epistemological access (see below)
- Internal: Support provided either through an extended curriculum or add-on support

Table 1 below shows how the different types of support differ between developed and developing countries using Southern Africa as an example.

As can be seen, programs are commonly outsourced in developed countries while universities in Southern African countries feel the need to take institutional control of the programs, probably to ensure that students exiting the access programs enroll in their institutions.

Accounts of the purposes of the programs differ but common elements are:

- The development and provision of quality SET education, particularly for students from disadvantaged backgrounds
- Delivery of SET education for meaningful employment for all
- Provision of alternative access routes to students who may not otherwise have had the opportunity to participate in tertiary study
- Increasing the pool of competent STEM graduates



Access of Historically Excluded Groups to Tertiary STEM Education, Fig. 3 Categorization of access programs (Adapted from Osborne 2003)

Access of Historically Excluded Groups to Tertiary STEM Education, Table 1 Comparison of types of support in developed and developing countries

Types/characteristics	Developed countries	Southern Africa
Systemic	4	1
Flexible	6	2
Inreach in-house	9	36
Inreach outsource	6	3
Outreach	25	3
Total	50	45

- Provision of the STEM-specific and more general skills and knowledge for success at tertiary study
- Providing outcomes relating to more than content alone – for example, ability to communicate, problem solve, and work as part of a team
- Increasing the knowledge base and confidence of students in STEM fields

Program Ideologies

The mode of operation and success of the program depends on the ideology associated with the access courses. These ideologies would be closely linked to ideologies of admission, as those in access programs are those who do not gain direct admission.

Brennan (1989) outlines four ideologies of admissions:

1. Relation of admissions to the reputation of institutions: The ability to attract good students is a sign of the institution's quality and is thus easily linked to the performance of the school leavers admitted.
2. Emphasis on equity: The concern is with fair competition for places, so admission to higher education becomes an award for diligence. Nonstandard routes into higher education other than access programs are suspect because they allow admission through unfair means.
3. The social engineering approach: Like the equity approach, it is concerned about equality of opportunity but wishes to level the playing fields by recognizing that some applicants are disadvantaged. Concern is about the social composition of the cohorts admitted.
4. The "shortage-of-students" approach: This arises when universities have difficulty filling places with conventionally qualified students.

A useful concept to describe the essential nature of access work has been provided by Morrow (1994) who coined the term "epistemological access" to the university. Essentially the term describes the extent of access to the culture of the institution. This relates to working to make students excel rather than avoid failure. It highlights the importance of making the program part of the academic enterprise, rather than isolating it.

This issue goes to the heart of epistemological access – students need to become part of the community of practice.

Grayson (1996) translates epistemological access into pedagogy as follows:

- Reasoning and practical skills must be taught explicitly.
- Learning must be rooted in specific content.
- Thinking and reasoning skills needed for science must be identified and explicitly taught.
- Disciplines should be broadly integrated.
- Teaching and learning are interactive.
- Content should be restricted in scope and covered in depth so as to promote conceptual understanding.

Relationship to Higher Education Policy

Richardson (2000) has designed a model of institutional adaptation to student diversity, shown in Fig. 4 (Rollnick 2010, p. 32).

Richardson (2000) suggests that when an institution is put under pressure to accommodate diversity, they initially respond by behaving in a reactive fashion (Stage 1), emphasizing recruitment and admissions and providing extrinsic support such as financial aid, without the deeper support structures needed to retain nontraditional students. Such reactive strategies are of necessity shallow and result in a revolving door admissions policy.

When these strategies fail, the institution becomes more strategic (Stage 2) and responds by trying to change the students in such a way that they provide a better fit for the institution. Stage 2 is characterized by outreach, transition programs, and the use of mentors who have already been successfully socialized into the institution's culture. The improved socialization in the institution may result in improved retention, leaving the institution satisfied that they have successfully managed a transformation process.

Stage 3 strategies, which require the institution to adapt its practices to take account of a changing student population, can only take place in the context of transformative state policies combined with committed institutional leaders. Stage 3 strategies are characterized by a change in culture of the university resulting in new curricula (or curricula adjusted to changing demands in the outside societies) and new pedagogies.

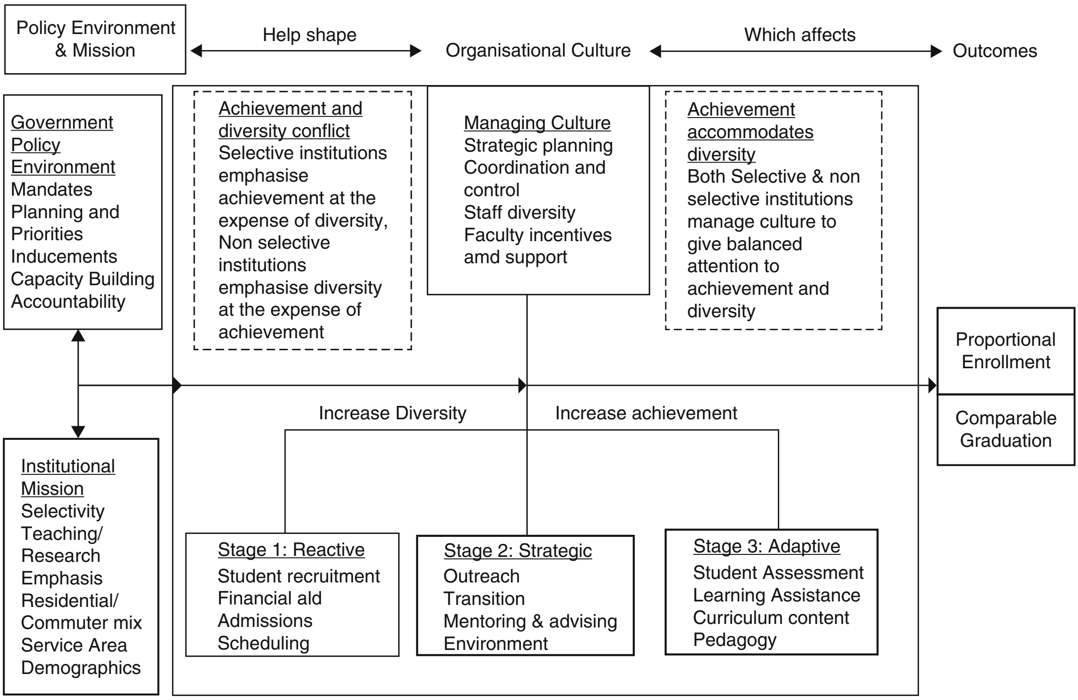
In countries where change is slower, it is easier for institutions without a long history to achieve this transformation. So traditional elite institutions would experience more difficulty in adapting in this way. However in a society where rapid social changes have taken place, state policies exert pressure on the institutions to change.

Richardson cites various characteristics of effective programs in the hard sciences and medicine:

- Provide students with more time to master the same material
- Use socialization experiences primarily to contribute to academic objectives rather than as ways of protecting the student from the campus environment
- Involve academic staff members in curricular reform to articulate access programs with those involving advanced work
- Emphasize changes in pedagogy to increase student success rates

Grayson (1996) outlines six different areas in which access students experience difficulties:

- Background knowledge: Mainly mathematics and language, but also general knowledge gained from living in an inquiring environment
- Attitudes: Rote learning, accepting knowledge without question
- Behaviors: Failure to do homework and preparation, failure to seek help, poor time management, lack of punctuality, meeting deadlines, becoming dependent on the lecturer, not studying with peers
- Cognitive skills: Logical reasoning, critical analysis, interpretation, and abstract representations
- Practical skills: Lack of experience in laboratory
- Metacognitive skills: Monitoring own thinking/understanding, studying effectively, responding to particular demands of a task,



Access of Historically Excluded Groups to Tertiary STEM Education, Fig. 4 Model of institutions adaptation to student diversity

making unrealistic assessment of requirements and own performance

The above shows that the difficulties are only partially cognitive and intimately associated with epistemological access to the university as outlined previously. Recognition of this has had an impact on the content of the curriculum in most access courses. Most courses have the following elements: discipline-specific courses, mathematics, language support, life skills, and computer skills.

The importance of mathematics as a gatekeeping course for most science studies needs to be recognized. As mentioned above where these are absent, they frequently require extra attention and carry no credit when taken at university.

Language support takes many forms at different institutions. More superficial approaches consider the required program to target technical English, while others recognize the deeper issue of changing discourse and communicative competence. Most programs recognize the need to integrate the language support into the teaching of the discipline-specific subjects.

In addition to purely academic skills, many programs address what could be termed "para-academic" skills to enable students to succeed and survive tertiary study. These skills address students' needs for assistance with metacognitive skills, behaviors, and attitudes as outlined by Grayson above. Some institutions offer these skills in a separate course or through counseling services as well as integrating them into the teaching of the courses.

Cross-References

- ▶ Code-Switching in the Teaching and Learning of Science
- ▶ Discourse in Science Learning
- ▶ Language and Learning Science
- ▶ Metacognition and Science Learning
- ▶ Retention of Minorities in Science

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Accommodation in Assessment

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Keywords

Effectiveness of accommodations in assessment; English language learners

The purpose of accommodation is to allow students to best demonstrate their development, understanding, and achievement. There is, however, a lack of consistency in the design, development, and provision of accommodation which is a controversial issue. The types of accommodation adopted include extended time such as time and a half, double time, or unlimited time; small group/individual assessment to reduce distraction to other test takers; providing test directions such as interpretation for students taking tests not in their first language or for English language learners (ELLs); test items read aloud or interpreted; and student sign response for those students having difficulty expressing themselves in writing. Further, there are accommodations in settings such that the environment setup is changed, which is a common practice for students who are easily distracted. Many of these accommodations are not limited to science but are also common in other subject areas.

Considerations of accommodation in assessment in science are recent. Other studies aim to identify the effectiveness of the various measures for accommodations in assessment. Effectiveness is measured or represented in a number of ways including student satisfaction, test score validity, and verifying scores from accommodated tests to see whether they measure the same attributes as the unaccommodated tests.

Cross-References

- ▶ Alignment
- ▶ Assessed Curriculum
- ▶ Assessing Students at the Margins
- ▶ Assessment Framework
- ▶ Assessment of Doing Science
- ▶ Embedded Assessment

Acculturation

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Acculturation is a concept borrowed from cultural anthropology and applied to education (Eisenhart 2001; Aikenhead 1996), in which teaching-learning is understood as cultural transmission-acquisition and meaningful learning is assumed. Within cultural anthropology, science has been described as a cultural entity (an ordered system of meaning and symbols, in terms of which social interaction takes place;

according to Geertz 1973). As a subculture of Euro-American cultures, Eurocentric science (ES) can be distinguished from other cultural ways of rationally and empirically describing and explaining the physical world (Aikenhead and Ogawa 2007).

Accordingly, conventional science education seeks to transmit the culture of ES to students so they can conceptualize, talk, value, and behave scientifically – being scientific. Two extreme reactions can result. Science-oriented students are eager to be identified with being scientific because their worldviews tend to harmonize with a worldview endemic to ES conveyed by school science (e.g., they often embrace a mathematical idealization of the physical world). The way these students' experience the cultural transmission-acquisition of ES is called ▶ *enculturation*, in which being scientific enhances their everyday world. However, for non-science-oriented students whose worldviews are discordant with a worldview endemic to ES in varying degrees, the school is attempting to get them to comply with being scientific and to significantly change or add to their self-identities and everyday thinking, more or less. This is a transmission-acquisition experience called ▶ *assimilation* (Aikenhead 1996). Most non-science-oriented students resist assimilation successfully.

Between the extremes of enculturation and assimilation lies the transmission-acquisition experience of *acculturation*: the selected modification of one's currently held ideas and customs under the influence of another culture (Aikenhead 1996). An ideal goal of school science acculturation is to have students master and critique ES without, in the process, diminishing their own worldviews, self-identities, and culturally constructed ways of knowing the physical world.

When participating in acculturation, a non-science-oriented student most often changes a concept or belief, or adds new ones, to their understanding of the physical world. A key phrase in the definition of acculturation is "selected modification," because selections can be made either in an explicit, informed, autonomous way or in an implicit, uninformed, pressured way. The former is called *autonomous acculturation* (Aikenhead 1996), while the latter could be seen as *coercive acculturation*.

Examples will help clarify these categories of acculturation. A non-science-oriented student experiencing autonomous acculturation makes a decision in a fairly deliberate way to adapt from the culture of ES attractive aspects of being scientific. For instance, a non-science-oriented student takes on sufficient aspects of being scientific to become more critical of science-related advertisement claims. Another example is non-science-oriented American Indian students adding the scientific concept of disease to their Indigenous understanding of poor health (i.e., the imbalance among the physical, mental, emotional, and spiritual dimensions of humans) because they anticipate gaining power by addressing ill health from two cultural perspectives. In both examples, students autonomously appropriated knowledge from the culture of ES. Their decisions were guided by intellectual independence.

On the other hand, selections can happen under mild coercion, that is, made subconsciously or without full cognizance of the consequences. Intellectual independence is mostly absent. An example of coercive acculturation is a situation in which reductionist and/or mechanistic metaphors in ES replace a student's holistic and/or aesthetic images of nature and thereby causing angst for the student. Another example is an isolated American Indian community purchasing a satellite dish, only to discover that the next generation of children has become fluent in English at the expense of their native tongue and therefore losing a critical aspect of their culture. In other words, the community has experienced coercive acculturation into mainstream American culture by the community's selection of a technology without understanding the consequences. If instead of offering satellite dishes, the dominant society implemented residential schools harmful to American Indians or refused to include American Indian perspectives in school science courses, that act would be assimilation.

The line between coercive acculturation and assimilation is a vague one. On the one hand, coercive acculturation is associated with inadvertent action by educators who perhaps have not critically considered how their policies or teaching indoctrinate non-science-oriented students and how these students risk unconsciously altering their self-identities or worldviews without the benefit of considering the consequences. On the other hand, assimilation is associated with actions by educators who achieve their *intended* consequences of indoctrination.

The degree to which non-science-oriented students actually incorporate being scientific into their self-identities and everyday subcultures reflects the degree to which acculturation has taken place (Aikenhead and Jegede 1999). Such students can be empowered to draw upon the culture of ES in appropriate situations, such as working at a job or profession, judging a -science-related personal or social issue, participating in a science-related event, or making sense of one's own community or society increasingly influenced by ES.

The process of acculturation, however, does *not* apply to those non-science-oriented students who are able to acquire enough content from the culture of ES to pass science courses but without understanding that content in any meaningful way, in other words, without integrating aspects of the culture of ES into their self-identities or everyday world. Those students tend to avoid any of the cultural transmission-acquisition processes related to science education. The process these students follow has been labeled "playing Fatima's rules" (Aikenhead 1996), and the "rules" comprise various strategies of resistance against any attempt to enculturate, acculturate, or assimilate these students.

Cross-References

- ▶ Alienation
- ▶ Borders/Border Crossing
- ▶ Classroom Learning Environments
- ▶ Cultural Change
- ▶ Cultural Imperialism
- ▶ Cultural Influences on Science Education
- ▶ Cultural Values and Science Education
- ▶ Culturally-Relevant Pedagogy
- ▶ Culture and Science Learning
- ▶ Emotion and the Teaching and Learning of Science
- ▶ Epistemology
- ▶ Ethnoscience
- ▶ Indigenous and Minority Teacher Education
- ▶ Indigenous Knowledge
- ▶ Indigenous Knowledge Systems and the Nature of Science
- ▶ Indigenous Students
- ▶ Indigenous Technology
- ▶ Learning of Science – A Socio-Cultural Perspective
- ▶ Multiculturalism
- ▶ NOS: Cultural Perspectives
- ▶ Science Curricula and Indigenous Knowledge
- ▶ Socio-Cultural Perspectives and Characteristics
- ▶ Socio-Cultural Perspectives on Learning Science
- ▶ Teacher Preparation and Indigenous Students
- ▶ Teaching and Sociocultural Perspectives
- ▶ Values and Indigenous Knowledge
- ▶ Values and Learning Science
- ▶ Values and Western Science Knowledge
- ▶ Values in Science

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Achievement Differences and Gender

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Achievement Differences and Gender

It has been asserted that achievement differences in certain fields – the sciences in particular – can be explained by innate differences in boys' and girls' ability, specifically their representation among those with the highest ability in mathematics. Although some research evidence supports this hypothesis, scholars have also argued against this claim. For example, a meta-analysis of US state assessments found that female and male 2nd through 11th grade students did not significantly differ in mathematics performance, but limitations in these data did not allow for analyses of the areas in which extant research finds that gender differences may be more likely to emerge – complex problem solving and advanced mathematics (Hyde et al. 2008). If not ability, what does explain variation in male and female secondary school students' selection into scientific disciplines, in postsecondary and beyond?

Importantly, extensive research suggests that gendered differences are most likely shaped more strongly by social, psychological, and cultural forces rather than biology. Recent research shows cross-national variation in sex segregation of career fields as well as in the level of gender differences in students' performance on mathematics assessments. Importantly, differences in science achievement and choice of career pursuits in these fields appear to develop over time.

Socialization begins early in life, including messages girls and boys receive about what careers are appropriate for them. Notably, US girls perform as well as US boys in mathematics and science in elementary and early secondary school on the National Assessment of Educational Progress (NAEP). Male students have been found to slightly outperform females on these tests at the end of high school, particularly on advanced curriculum. One hypothesis for the emergence of this gap could be that males are simply stronger in advanced mathematics and science than females.

But another pattern emerges in secondary school that suggests a different causal path. It is in secondary school that students can choose which courses to take, and females may be less inclined to pursue areas that are not associated with female success. Indeed, males have been found to enroll in more advanced secondary school physics courses than females. Notably, of those students who completed the most advanced mathematics and science courses and went on to major in the most male-dominated sciences – physical sciences, engineering, mathematics, and computer sciences (PEMC) – there is a negative association between female gender and tenth grade perceptions of their mathematics ability on their chances of selecting these majors instead of other college majors – controlling for mathematics ability and other potentially confounding factors (Perez-Felkner et al. 2012). This finding corresponds with research on career task values. When children internalize their society's expectations for their career-related achievement, they may in turn devalue and turn away from tasks related to areas in which their group is not expected to perform well (e.g., mathematics for girls) (Eccles 2011). It may be that gender differences in scientific career achievement can be explained by these social psychological differences in female and male students' orientations to mathematics and science.

Cross-References

- ▶ Attitude Differences and Gender
- ▶ Careers and Gender
- ▶ Gender
- ▶ Gender-Inclusive Practices
- ▶ Interventions, Gender-Related
- ▶ Participation, Gender-Related
- ▶ Socio-Cultural Perspectives and Characteristics

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Achievement Levels

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Keywords

Achievement levels; Advanced International Benchmark; High International Benchmark; Intermediate International Benchmark; Low International Benchmark; TIMSS

Achievement levels are performance standards describing what students who achieve a given level on a scale typically know and can do. They refer to academic achievement providing a context for interpreting students' scores on different assessments. Each achievement level description reveals a picture across a broad range of performance levels with corresponding details related to the framework. They are cumulative, students performing at one of the superior levels also displaying the competencies associated with the lower levels.

For example, Trends in International Mathematics and Science Study (TIMSS) utilizes scale anchoring procedure to summarize and describe achievement at four points on the mathematics and science scales – Advanced International Benchmark (625), High International Benchmark (550), Intermediate International Benchmark (475), and Low International Benchmark (400). The first step was to identify those students scoring at each cut point followed by determining which particular items anchored at each of these benchmarks. To determine which items students at each benchmark are most likely to answer successfully, the percent correct for those students was calculated for each item. The delineation of sets of items that students at each international benchmark are very likely to answer correctly and that discriminate between adjacent anchor points takes into consideration the percentage of students at a particular benchmark correctly answering an item and the percentage of students scoring at the next lower benchmark who correctly answer an item. The experts based on the items' descriptions within each benchmark elaborated the descriptors according to the frameworks. The result is a summary of the international learning outcomes in terms of acquiring skills and knowledge reflecting demonstrably different accomplishments by students reaching each successively higher benchmark.

Cross-References

- ▶ Assessment Framework
- ▶ Cut Scores
- ▶ Scale Scores
- ▶ Third International Mathematics and Science Study (TIMSS)

Action and Science Learning

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The Actional Turn in the Sciences of Culture

We argue that an actional turn is currently taking place across all the social and human sciences – the "sciences of culture." By "actional turn," we mean the fact that each studied phenomenon is seen through practice, as a practice.

For example, Science is studied “in action” (Latour 1987), in a research process which privileges Science “in the making” over “ready-made” Science.

In Educational Sciences, in particular Science Education Research, this conception has two major consequences. The first one refers to the fact that, in order to understand Education, one has to understand two fundamental actions, the teaching action and the learning action, both in their conceptual structure and their empirical unfolding here and now. The second consequence rests on the same logic and refers to the knowledge ontology within the educational process. This knowledge is not seen as a thing, but as a praxeology (Chevallard and Sensevy 2014): a praxis (a practical action) and a logos (a body of discourse) related to this action. Knowledge is seen as a living organism, and the researcher’s work consists of understanding the life of knowledge (Tiberghien et al. 2009) from the sphere in which it has been shaped in scientists’ practice to the settings where it is transmitted, as it is enacted and embodied in student’s and teacher’s practices.

What Kind of Action?

We argue that acknowledging this actional turn in Science Education Research is a point of departure that enables the educational process to be conceptualized in a different manner. In this way, the Joint Action Theory in Didactics (Sensevy 2012; Ligozat 2011; Tiberghien and Malkoun 2009; Venturini and Amade-Escot 2013) conceives the educational action as a specific kind of joint action, in which the teacher’s action and the student’s action are deeply interrelated through the growing of common knowledge.

It is important to note that the Joint Action Theory in Didactics (JATD) does not see these actions as symmetrical. In particular the teacher’s work consists of managing learning situations in which the current student’s strategic system of action (the didactic contract) may enable him/her to deal with the emerging symbolic structure of the knowledge in the problem at play (the didactic milieu), so that the student may endorse the specific thought style (Fleck 1981; Sensevy et al. 2008) that this knowledge embeds. In that way, in JATD, the art and the science of teaching could be seen as a way of monitoring the relationship between the student’s work and the milieu.

The Didactic Joint Action: What Methodological Consequences?

Such an “actional ontology” of the didactic action entails some consequences from a methodological viewpoint. Among them, it is important to emphasize the following idea. If didactic joint action is conceived as a fundamental dialogic action between the teacher and the student through the piece of knowledge at play in the didactic activity, the research method needs to document this specific relationship. That is to say that a prominent place is given to the study film (Tiberghien and Sensevy 2012), which enables the researcher to describe and understand the relational tridimensional patterns that links the knowledge growing, the student’s action, and the teacher’s action. Such study films constitute the central component of what one may call hybrid text-pictures systems (Sensevy et al. 2013) in which different kinds of “pictures” (e.g., systems of photograms) and different kind of “texts” (comments, content analysis, statistical analysis, etc.) are thought of in mutual annotation and as specific to these systems. One of the major features of a hybrid text-picture system is that it puts in relation different scale levels, from the briefest transactional moment to the longest duration teaching-learning process. Some of these hybrid text-pictures systems may be considered as practical exemplars (Kuhn 2012) and, according to Hacking (in Kuhn 2012), be seen as “shared examples” in Kuhn’s essential perspective.

Cooperative Engineering: Research as a Joint Action

In the first three parts of this entry, we have focused on didactic joint action, which refers to knowledge transactions between the teacher and the student.

As we previously argued, this “actional turn stance” stemmed from a more general conception pervading through the sciences of culture. Within such an actional conception, the very process of research itself may be modified. In particular, a prominent place has to be given to design-based research according to the fact that the sciences of culture are in part engineering sciences, sciences of the artificial, which help modify human practices in order to make them achieve new ends for a better life. The consequences of such a viewpoint for science education may lie in the development of a specific form of design-based research, cooperative engineering (Sensevy et al. 2013), which can be characterized by the common definition of educational ends between teachers and researchers, and by their common proposal and test of work hypotheses relating to the students’ learning. This teacher-researcher joint action does not erase the differences between teachers and researchers. On the contrary, it asks for a common grasp of consciousness of these differences. But it rests also on the sharing of a common stance, that of an engineer of the educational action, an engineer of the culture.

Cross-References

- ▶ Didactical Contract and the Teaching and Learning of Science
- ▶ Evidence-Informed Practice in Science Education
- ▶ Milieu
- ▶ Transposition Didactique

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Activity Theory and Science Learning

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Keywords

Activity theory

What Is Activity Theory?

Activity theory represents the application of principles of human development and learning from the Russian psychologist Lev Vygotsky and his contemporary interpreters such as Yrjö Engeström (1987) and Michael Cole (1996). While this ensures that activity theory enjoys a rich albeit evolving philosophical grounding, it also confronts science educators with challenges when appropriating it into their classrooms. Activity theory is not a monolithic template or a well-bounded set of research techniques that one can quickly extract from a textbook and reassemble for use. Rather, it is better considered a spectrum of ideas – without achieving complete consensus among researchers – that are located within the sociocultural learning tradition. Its unfamiliarity to those trained in Western psychology may have resulted in either indifference to activity theory or its use in ways that some experts would deem as unorthodox if not erroneous. While this state of affairs is understandably confusing for educators, activity theory can offer those following Vygotsky's method of research a number of guidelines for organizing science teaching–learning that are respectful of how people learn and collaborate in tandem with cultural artifacts/tools. Together with its potential for addressing long-standing theoretical and practical dilemmas in science education research, this framework has already found resonance among those from the Learning Sciences, computer sciences, and organizational and workplace learning communities.

Within the field of science education, one has to realize that the sociocultural tradition in learning has only gained acceptance over the last 15–20 years. Placing issues of language, social interactions, and culture and history in the foreground, advocates here downplay the emphasis on achieving and assessing visible outcomes of learning where intelligence is believed to be housed within the mind. This sea change regarding the origins and development of learning as processual or transactive during activity rather than solely biological was sparked by the appearance of Vygotsky's writings in English. Activity theory can thus be said to be the most sophisticated and interdisciplinary elaboration of Vygotskian thought for education currently, which itself draws upon dialectical-materialist underpinnings in Marxism. Remembering its long intellectual heritage enables one to quickly appreciate its ontological and epistemological assumptions as well as generate applications of activity theory that are more faithful to its practice-oriented, transformatory stance. Two ideas in dialectical materialism are acknowledged as salient in activity theory:

(A) **The reciprocal relationship between acting in the world and being transformed psychologically and sociologically by this very process**.

Being within, relating to, and acting on the material world, that is, when pursuing the conditions for life, human agents are simultaneously transformed at the level of the individual (the creation of consciousness [i.e., learning], personality) and at the level of the collective (the beginning of division of labor in society). On the one hand, it affirms that there is no escape from a materialist account of learning; without the prior concrete world of experience, there would be no knowledge to grasp or exhibit. As some have put it, there is no knowledge without praxis. The Cartesian rift between mind and body (and other dualisms) is thus healed through an activity theoretic perspective. On the other hand, there is another dialectical relationship; through their labor individuals serve both individual and collective needs; indeed labor creates the very conditions for society to function just as social institutions open up opportunities for individuals to contribute and sustain themselves in diverse ways. Unlike how other creatures usually interact with nature in a direct, stimulus–response manner, humankind manages or mediates these relationships of self and others through created and ever-changing tools and practices to satisfy human needs. It is argued that all higher psychological functions such as motivation, identity, and sensemaking are irrefutably mediated by interactions with others and shared artifacts (e.g., language) – learning as a sociocultural process precedes biological development as Vygotsky maintained. Individual learning therefore contributes towards expanding knowledge in/for others at the same time as established knowledge enables any newcomer to appropriate these through instruction without necessarily rediscovering this wisdom de novo.

Because not everyone contributes in the same manner in/to society, a division of labor therefore exists. The totality of these societal activities (from which activity theory properly derives its nomenclature), however, serves in part to reproduce as well as be the engine for change in the world. And because these social practices form the basis of culture that individuals can orient towards, participate in, and perhaps depart over the course of time, the adjective "cultural-historical" is properly attached to activity theory (i.e., the popular acronym "CHAT") to underscore their explanatory significance. Psychology has traditionally eschewed matters of culture and history in accounting for learning but activity theory instead conflates them as it is felt that mental processes are utterly dependent on the former. This again affirms the materialist-dialectical core of activity theory; change in any aspect of the material world or social practices and mutual changes in human functioning and cognition will ensue. Hence, when studying skilled actions, activity theorists pay careful attention to expertise occurring within a specific environment that they regard as ontologically indistinguishable although kept separate for analytical purposes by necessity. Rather than just privileging the actions of human agents, activity theorists prefer to scrutinize that particular societal activity as a whole and then interrogate these subsets of activity through various ways: what is happening or being changed there, by whom, through what means, and for what (historical) purposes. This close as well as practical approach towards understanding learning in a complex world (e.g., through interlinking levels of individual/collective) is a distinguishing feature of activity theory.

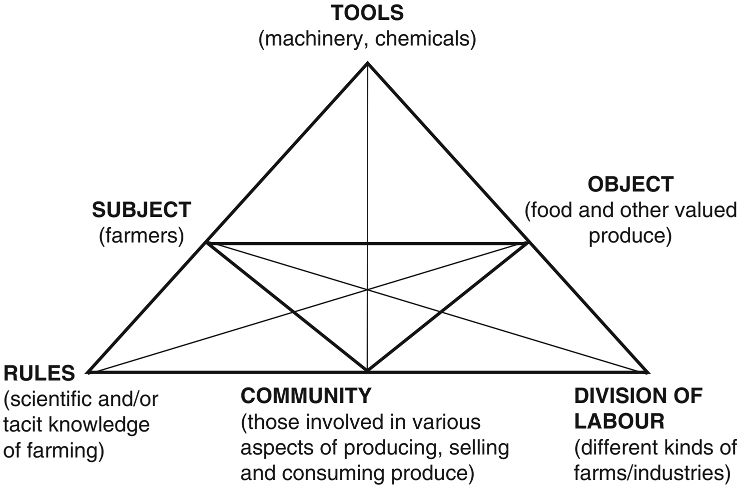
(B) **The transformation of the world should be a primary activity, not its mere contemplation**.

This is an extension of the former point; it is not sufficient to merely describe or philosophize about the world at the level of ideas. Instead, one has to participate with others (e.g., to describe, critique, explain, expose power) to author one's context in a life-affirming, creative, and humane sense (Roth 2010). The material world will pose all sorts of resistance to our desires (we cannot fly like birds), but this does not hold true for social phenomenon, which is amenable to human intervention/change that gave rise to it in the first place. True to its Marxist roots, activity theory is distinguished from other theories of learning in its problem-solving, expansive, and improvement-seeking nature that have been used to critique many situations and processes both in and out of school (Langemeyer and Nissen 2011). This has provided activity theory with intrinsic appeal as both a theory of instruction and a model of learning, not only for those concerned with social justice and equity agendas. A hypothetical example might serve to tie the two aforementioned key ideas in dialectical materialism: Annotated lesson plans have recently been recommended as an ideal vehicle for building a shared knowledge base for school improvement. When a teacher is motivated to submit something towards the pool of lesson plans (i.e., a knowledge product), not only does her school department benefit in enlarging the pedagogical repertoires for the collective to tap upon, but student learning (and school climate) also improves, which is the raison d'être for teachers. Identifying any obstacles together with the enablers in the overall system can provide leverage to sustain this virtuous cycle of innovative activity. Knowledge (better seen as a verb or process) in the activity system of schooling thus increases as the lesson plans are continuously revised by individual teachers engaging with different classroom/school settings and subject areas. Better yet, when students are jointly engaged in learning with teachers such as during aspects of Assessment for Learning, the joint transformation of their lifeworlds in the zone of proximal development is made manifest – does it really matter who is doing the teaching–learning now when everyone benefits?

How Can We Describe and Use Activity Theory?

Research in activity theory has fallen into two main thrusts: (1) a method and a methodology to research human psychology during engagement in everyday activities and (2) a practical intervention method for redesigning work conditions in organizations including that of schools. There are finer distinctions and a specialized vocabulary available too; the object (that part of the world to be changed) of activity is that which motivates participation in the activity system to produce an outcome. It makes no sense to speak of activity without an object for people would not undertake any actions or efforts to change the object in the first instance; they are mutually constitutive. While these actions that serve the object(s) are conscious behaviors, there is another lower level of activity that can be described – operations – which are unconscious processes (without any connotations of psychoanalysis). These three important hierarchical levels – activity, actions, and operations – are dialectically linked, just as an object is linked in a similar way to its subject (i.e., human agents). A classic example here was provided by Vygotsky's student A. N. Leontiev who spoke about the primeval collective hunt; hunters and beaters are united by a common object (to obtain food) even as they perform different and distributed actions during activity.

A more recent but highly influential heuristic known as the activity triangle has similarly proven to be an easy entry point into activity theory as seen in Fig. 1 below. Building on the fundamental concept of mediation, the subject focuses on the object using certain tools (both real and symbolic). This part of the activity system is characterized by production, whereas during consumption, exchange, and distribution, other moments/elements are brought to bear such as the rules,



Activity Theory and Science Learning, Fig. 1 A depiction of an activity system – the fundamental unit of analysis – using agriculture as an exemplar. Farmers (subject) plant crops using machinery and chemicals (tools) to produce food and other valued produce (object). This process follows scientific and/or tacit knowledge of farming (rules) and articulates with those involved in production/exchange/consumption practices such as salespersons, irrigation experts, and restaurateurs, etc. (community). No single farmer can/might produce everything and is thus reliant on others for equipment, building materials, seeds, and so forth (division of labor) community, and the division of labor. Important to note is that they are again all dialectically linked; while we can focus on a single moment in the activity system, one should recall that the others are always residing in the background.

The activity triangle has achieved an iconic status although approaching activity theory this way is not without some pitfalls. For example, it tends to emphasize the synchronic rather than diachronic aspects of activity just as it has tempted some to be indiscriminate in identifying the various moments in an activity system that exist in a parts–whole relationship. These problems are partly due to the subtlety in defining "activity"; the English language is unable to differentiate the German/Russian understanding of societal activity or work (*Tätigkeit*/*deyatel' nost*) from mere effort, being engaged or busy, which is known as *Aktivität*/*aktivnost*. Hence, educators are frequently puzzled over the most appropriate level of analytical focus – the national system (i.e., schooling), the school/district, or the classroom/groups of students – because all three "activity systems" are amply represented in the literature, sometimes even within a single manuscript.

Besides the three hierarchical levels of activity and the different moments in an activity system, another fruitful concept is the idea of contradictions. These are frequently described as inner contradictions and are not to be confused with issues, conflicts, or problems of a superficial nature. Contradictions per se do *not* cause change; instead, they act as both resources and products of human agency during transformations of activity systems (i.e., when the object is changed). These dilemmas that are cultural-historical in origin exist at the collective/societal level and appear in four kinds. For instance, schools undergoing STEM reforms might encounter a lack of resources (a primary contradiction), learning mismatches between learners and teachers (secondary contradiction), unrealistic policy mandates coming from external authorities (tertiary contradiction), and possibly graduating students ill-prepared for science-related careers (quaternary contradiction). Presently, one reads about third generation (at least two interacting activity systems, tensions, dialogue, etc.) and fourth generation activity theory (inclusion of emotions, identity, ethics) although there is no firm consensus on their characteristics. What perhaps can be agreed is that activity theory tries to explain how sensemaking and development occur at the intersection of people acting in and on their sociomaterial environments.

Activity Theory and Science Education

In general, activity theory has been commended for its ability to handle issues of contexts, complexity, power and politics, identity and emotions, and the rapidity of educational change among others. Yet, the inroads into science education have been patchy without any person, group, or research program who can be consistently associated with this framework save for a select few such as Wolff-Michael Roth (2010). Science educators would find interest in some of the advantages of using activity theory in the discipline that are summarized below (see Roth et al. 2009).

1. To understand tool mediation in teaching and learning

   Most studies in this category have examined the use of computers and software as mediators of science learning, including the role of contradictions in the activity system. The use of psychological/thinking tools such as scientific representations has also been an area of interest. And treating science as practice in the new STEM standards in the United States finds much alignment with understanding activity as equivalent to the production, consumption, and exchange of knowledge.

2. To make visible normally invisible structures, processes, relations, and configurations

   It is the intent of educators here to provide accounts of learning that are more inclusive, to understand how schooling in society mediates individual learning. Urban science education or those initiatives that advocate science for all or with science–technology–society emphases immediately come to mind. Important but less invoked themes of race, class, and gender that play over different timescales for learners are now salient. This is the strength of activity theory when it draws culture and history into our explanations of learning.

3. To investigate issues concerning a larger system or across systems

   Even though the focus of analysis has often been the single activity system, activity theory allows researchers to zoom in and out, to make linkages between nested and overlapping activity systems (i.e., boundary objects) and give greater breadth and depth to analyses. For example, science teachers are impacted by district and societal demands and the forces of globalization even though classrooms might seem like rather isolated activity systems to many.

4. To rethink and empower science learning

   Squarely within its transformative stance, past research in this category has shifted attributing (dis)ability in purely personal terms to incorporate the sociocultural dimensions as well. Research in science education here has studied informal learning environments (e.g., environmental groups) where deep motivation and surprising levels of science expertise are displayed among students that have been written off by formal institutions.

5. To create structures and collaborations to facilitate change

   Notable here is the vast amount of work done on coteaching and cogenerative dialogs in urban science education where activity theory is used as a theory for praxis and theory of praxis. Stakeholders in environmental or workplace disputes have also been brought together using this framework to good effect because it allows for multi-voicedness in uncovering the contradictions and the heterogeneous forms the object of activity might assume.

Ongoing Difficulties with Activity Theory

One persistent dispute concerns the unit of analysis in activity theory. If we assume that activities are properly those that sustain human society, then the unit of analysis that Vygotsky championed tends towards larger, more encompassing categories such as schooling, agriculture, law, and so on. It is definitely not at the level of the individual which classical psychology has favored. Be that as it may, this has not prevented the examination of classrooms or curricula programs using activity theory to unpack the systemic contradictions there or to pinpoint specific individuals as the subject of activity. Similarly, identifying the elements or moments within the activity triangle has been seen as problematic because these are believed to be dialectical in nature thereby impossible to analyze or comprehend as stand-alone entities. Again, such a purist stance has not been consistently applied; individual elements within the triangle have been the topic of past research. In short, activity theory has philosophical underpinnings that are not easily understood (e.g., privileging knowledge as process), and thus it sometimes seems too encompassing to the point of being vague as well as too specific on other occasions with claims made that are unsupportable by the data. However, it is now increasingly accepted that micro-level phenomenon feed and support macro-level events which themselves offer affordances for the emergence of new or existing structures – both levels are analytically productive as what Vygotsky had proposed although declaring one’s theoretical commitments here is needed.

Contradictions have also long been irresistible as an explanatory variable when accounting for problems and resistance to change in activity theoretic research. Yet, fidelity to these being an inner, systemic contradiction which the use and exchange value of all objects exemplify is not often adhered. The final candidate for why activity theory is so frequently misunderstood is most likely its inherent dialectical structure; learning changes from being largely attributable to individual qualities or accomplishments to being a social, collective venture. A dialectical perspective likewise suggests a needed corrective against a form of smugness in sociocultural research – our interpretations of the social world are but works in progress, by-products of a particular age and place and of fallible human beings. Certainly, this lack of closure and certitude in taking a dialectical stance will be frustrating to many.

Overall Assessment of Activity Theory in Science Learning

What are science educators to make of activity theory? It has been claimed to be able to overcome dichotomies that have plagued education such as individual/collective, body/mind, intra-/inter-psychological, and so forth. While these goals are still being worked out, at the very minimum it sensitizes us to view learning as an ongoing orchestration of people and cultural artifacts in practices (activity systems) where the past and the present are intertwined. It also inspires us to see the potential for human(e) development when societal contradictions are surfaced, critiqued, and overcome. This is an exciting but extremely difficult endeavor; human learning is multidimensional and complex, which science educators have overwhelmingly theorized at the level of the individual learner. Activity theorists will therefore continue to plod on in their research long after where Vygotsky had left off.

Cross-References

- ▶ Assessment Framework
- ▶ Communities of Practice
- ▶ Dialogic Teaching and Learning
- ▶ Emotion and the Teaching and Learning of Science
- ▶ Heterogeneity of Thinking and Speaking
- ▶ Socio-Cultural Perspectives on Learning Science

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Adaptive Assessment

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Adaptive Testing

Adaptive assessment can be defined as any type of assessment that is tailored specifically to each examinee, based on their performance on previous items on the assessment. Most adaptive assessments are based on the theories and advances of Item Response Theory (IRT). More specifically, in IRT the examinee ability estimates, as well as item characteristics such as the item difficulty, are placed on the same continuum. This allows for the administration of items that are matched to the estimated ability level (θ), of each examinee, at each point of the assessment. Therefore, adaptive assessments allow for the administration of items that are targeted to the ability level (or trait level) of each examinee, which enables the estimation of more accurate examinee ability estimates. For example, if an examinee responds correctly to item 1, their estimated ability will increase, so the second item that will be administered will be of higher difficulty than the first item. If the examinee responds incorrectly to item 2, the examinee's estimated ability will drop slightly, so the third item that will be administered will have a level of difficulty in between the difficulty levels of items 1 and 2. By administering more items that are specifically targeted to each examinee's ability, a more accurate ability estimate is achieved.

Adaptive assessments come in contrast to linear, nonadaptive assessments where all examinees respond to the same or equivalent forms of a test in a predetermined order. One problem with nonadaptive assessments is that the majority of the items administered are targeted to examinees in the middle of the ability continuum. Therefore, linear tests typically include a large number of items of average difficulty and few items of lower and of higher difficulty. This creates problems for the accurate estimation of examinees at the extremes of the ability continuum, as low ability examinees will find the items at the middle of the ability continuum too difficult, whereas high ability examinees will find such items too easy. Consequently, nonadaptive assessments tend to provide little information for high-achieving and low-achieving examinees, the ability estimates of whom therefore include large amounts of measurement error.

Some of the advantages of adaptive assessments are those of increased measurement accuracy for examinees at all ranges of the ability continuum and item efficiency since fewer items are needed to reach the same level of accuracy as with linear tests. Additional advantages of adaptive assessments when they are administered electronically are those of immediate scoring and reporting and more frequent test administrations.

Some disadvantages of adaptive assessments include (a) the considerable initial costs of creating and calibrating large item pools that are needed for such assessments, (b) the inability of the examinees to go back and change their answers on most adaptive assessments which can create anxiety and frustration to some examinees, as well as (c) the security issues related to the compromise of the item pool due to the overexposure of some items.

Adaptive assessments can take various forms, based on their degree of adaptivity. Fully adaptive assessments are those where every item is matched to the examinee ability estimate with the only goal of increasing the amount of information on each examinee's ability. Other types of adaptive assessments administer groups of items together, as a testlet, and are called multistage adaptive tests. In other cases, due to various content constraints and problems with the overexposure of certain items, the assessments are called Barely Adaptive Assessments. For most types of adaptive assessments, due to the extensive computations that are required, they are typically administered on a computer and are frequently called Computerized Adaptive Tests (CAT).

Cross-References

- ▶ Assessment: An Overview
- ▶ Computer-Based Assessment
- ▶ Test

Advance Organizer

- ▶ Meaningful Learning

Affect in Learning Science

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Keywords

Affect; Content; Learning; Pedagogy

Introduction

In the current era of education where there is so much emphasis on cognitive educational outcomes and accountability, it can be difficult to recognize the importance of affect in learning science. Today, much of the public debate about and rationale for education sees the very basis of that education being best captured by accounts of instructional efficiencies, curriculum statements, lesson plans, and public records of pupils' performance. This is at best only a partial picture, and in such an era, we need to be vigilante in reminding ourselves of this. What is abundantly clear from research and practice is that affect has considerable influence over what happens in the classroom. Some emotions (such as joy, happiness, pleasure, delight, thrill, zeal, and gladness) act to potentially enhance learning and optimize student enjoyment and achievement, while other emotions (such as sorrow, boredom, sadness, distress, regret, gloom, misery, and grief) can close down concentration, deaden curiosity, and insight and in so doing can suppress learning. The affective and emotional encounters and relationships that we develop within pedagogies and with knowledge are profoundly and deeply important. Indeed, some would go as far as to say that they actually make science education possible (Alsop 2005).

Such an assertion is not really controversial. After all, there is overwhelming evidence from a diversity of academic fields and professional practices that teaching and learning are complex, both individually and particularly in their interactions. The focus here is on the mutually constitutive nature of cognition and affect. This may seem a small point; however, it is a shift in perspective with far-reaching consequences. In recognizing the importance of affect in knowing and knowledge, we start to dispel the view that science and science education is, can be, or ought to be based on reason alone. There is a long associated history, of course, in which affect is framed as mainly undesirable, as a potential obstacle to enlightened, objective thought (especially in science). In departing from this history and holding onto the importance of affect, we open up profound questions of objectivity and subjectivities, questions that more often than not accompany popular Western narratives of mind and body duality. There are legitimate arguments that such a departure leads one to a history of science that is more consistent with the practices of sciences than history often seeks to represent.

Affect has become represented by so many diverse theories and methodologies: Darwinism, Jamesian, cognitive and socio-constructive, phenomenological, neurological, psychoanalytical, and many other perspectives as well. These each bring languages, analytical categories, modes, and methods of explorations. In the history of science education, we have been drawn to a particular personal psychological perspective and have placed sustained attention on explorations of the construct of attitudes toward science. This significant and thoughtful body of work is the subject of another entry; so it is mentioned only in passing here.

Affect in Science Education

Studies of attitudes toward science have now been joined by a growing number of studies that adopt more situated perspectives in which affect is studied within particular contexts and settings. Such studies accentuate the situated nature of affect, stressing that emotions are always grounded in personal, social and cultural contexts. Of course, studies of attitudes are themselves set within particular contexts and times, and they often reference these within their methods. Today, attention is more commonly placed on studying learning embedded within identified and identifiable science education environments, such as school classrooms and laboratories. Studies of affect in science education (a term that is used here to denote these studies) are theoretically wide ranging and empirically diverse. Some researchers, for instance, attend to particular motivational constructs including self-efficacy, interest, task value, and achievement goals. These constructs have established definitions and lineage within particular educational learning theories. They have become firmly associated with enhanced learning outcomes. In particular educational settings, researchers explore the mediatory and moderating effects of such constructs with an overarching goal of better understanding how and why some instructional practices and approaches might be more efficacious than others. Here, for instance, emphasis could be placed on personal and environmental interactions as represented by interactions between intrinsic and extrinsic motivations (see Bonney et al. 2005).

Other researchers focus on specific instructional practices and processes. In these cases, affect is evoked as a vital consideration in understanding the relative advantages (or disadvantages) of some pedagogies – such as "hands-on" laboratory or practical work, animal dissections, inquiry-based learning, drama and role play, computer-based learning, and science field trips as well as many out-of-school activities. In particular instructional contexts, studies of pupils' emotions, and conceptual understandings employ a diversity of methods but are unified in stressing the importance of positive affect for deeper, more meaningful, and longer-lasting learning. Studies deploy a wide range of different measurements as a means to comment on the effectiveness (or otherwise) of instructional practices and innovations. Studies of free-choice learning and learning within informal contexts – to give very high profile examples – consistently highlight the importance of affect for learning. Indeed, affective considerations such as "interest," "curiosity," and "fun" are now widely assumed as an essential part of lifelong learning encounters with science.

There is a literature in science education in which affect is conceived more as an outcome rather than, or as well as, a process. In such cases, the goal of a learning encounter might be evaluated predominately in affective terms (such as building a positive relationship with science). Learning encounters with science can be seen in emotional developmental terms, using constructs such as Emotional Intelligence (EI), Emotional Quotient (EQ), or emotional well-being. EI and EQ are both associated with best selling popular texts, and there are a series of widely available standardized EI and EQ tests. Although these constructs remain controversial, in some educational jurisdictions, they can be appealing (particularly within associated discussions of character education and civic education).

Perrier and Nsengiyumva (2003) study of affect has a distinctive outcome focus of therapeutically reclaiming a sense of self as an "affective being." Set within the context of post-genocide Rwanda and extreme trauma, these pedagogues turn to inquiry-based science as a means to open up channels of communication, play, and joy. The predictability and safety of gathering biology and physics data offer a platform (they persuasively demonstrate) to restore and build learner's self-actualization and relationships with others. As the authors' note of their practice, "the most important goal, indeed, is not the quality of the scientific message or the pedagogy: the most important is whether the activities contribute to an actualization of the being" (p. 1123). Although this study was conducted nearly a decade ago, this account remains a powerful example of the potentially far-reaching emotional effects of science education.

Affect of Science Education

In the examples above, emphasis has been placed mainly on the socio-psychological; the focus has been on individuals within particular educational contexts and practices. There are a modest number of studies in which affect is framed more as a sociocultural or poststructural construction with particular social, cultural, and political origins. With this orientation, affect is represented as constitutive with particular cultures and social practices (including language, institutions, social relationships, behaviors, and histories). Research attention is drawn to analyzing these co-constructed educational cultural practices with their associated emotionalities.

Zembylas (2004, p. 301) in a 3-year ethnographic study of an elementary classroom, for example, draws attention to how a teacher's performance of emotional labor is an important aspect of science teaching. Teachers' emotional labor and their emotional metaphors function, in part, in creating inspiring cultures for teaching and learning. The teacher is willing to embrace "suffering" in the form of emotional labor because of seemingly "gratifying" emotional rewards. This study highlights teachers' agency in creating and maintaining socio-emotional cultures.

Orlander and Wichram (2011) study exposes some deep rifts between learners' lived emotional experiences and some of the sociocultural academic traditions of school-based science education. The focus here is adolescents' reactions to calf-eye dissections and sex education. The authors persuasively cast this as an instance in which learners' bodily reactions are central to meaning making in science. It also highlights the emotionally lively nature of some aspects of science education and raises questions of what emotionality is desirable or indeed, undesirable within science education practices.

Cultural and poststructural studies of affect raise significant socio-political questions concerning the emotional rules governing science classroom behavior and underpinning power relations that these rules support. For some time, feminist and postcolonial scholars have drawn attention to the politics of affect, exposing the legacies of Western patriarchal thought and institutional practices. Different authors theorize the political motivations that reinforce the seemingly undesirable nature of some emotions and the worldviews that this presupposes and actively supports. This raises a number of questions for science education, including whose emotionality gets to count in our practices? How? Why? What are the shorter-term and longer-term implications of more dominant emotional traditions for different groups of learners? Are practices in science education failing students because of the particular emotional (or emotion less) forms of knowing that are stressed in teaching? These questions are presently largely under-researched and call for much greater attention in the future.

Affect in Learning Science

As with all attempts to describe learning and education, there are associated theoretical and methodological conundrums. Our narratives of learning are at best partial and serve to illuminate particular aspects whilst leaving others underdeveloped. We make our way in the world through telling stories and these stories also make our worlds. Our primary story in science education is cognition, and we record and rightly celebrate the conceptual performances of learners. Yet there is a clear evidence base that affect and cognition are inseparable and mutually constitutive.

This entry has drawn attention to three broadly different orientations to the study of affect and learning science: attitudes toward science, affect in science education, and affect of science education. These orientations are not offered here as distinctive or categorical, but as illustrative and carry with them an invitation to explore how they might, or might not, be connected. While pupils' attitudes toward science have been widely documented (often and for many decades presenting worrying trends of decline) there is an open question as to how to best respond. Different authors, quite understandably, offer a wide variety of suggestions and these often make reference to changes in teaching and learning practices. As such, they assume a connection at some level between attitudes and situated experiences. However, much research suggests that individual dispositions and situated experience are very different. Attitudes can develop more slowly; perhaps over a longer period of time, while lived emotional experiences can be short lived, episodic, transitory and more immediate. In a recent study, for instance, Abraham (2009) records an increase in short-term engagement during practical lessons but this does not translate into longer-term changes in students' interest. One of his recommendations is that researchers need to develop much more realistic understandings of the potential affective benefits of practical work. Indeed, much evidence now suggests that the construct attitudes toward science and more situated studies of affect in science education are not as closely related as is often assumed. For instance, much research paints such a gloomy picture of students' declining attitudes to science and this is a source of legitimate concern. However, this research cannot be simply extrapolated to conclude that students are regularly having problematic emotional experiences in science lessons. Most science teachers, I am sure, spend considerable time seeking to make their lessons emotionally engaging and enticing.

Similar arguments can be made concerning sociocultural studies of affect (affect of science education). While the emotional natures of our practices remain largely under-researched, these natures raise a number of questions of how they might (or might not) influence learner's situated experiences and their general dispositions and attitudes toward science. It remains an open question, for instance, as to how ways of feeling that are legitimized and de-legitimized by classroom practices impact (or not) students' lived classroom experiences. Orlander and Wickram (2011) previously mentioned study serves to demonstrate that dominant cultural traditions can be quite different to pupils' actual educational experiences. The relationship between what teachers intend students to learn and what they do learn is both dynamic and complex. Exploration of the nature and consequence of possible connections between attitudes toward science, affect in science education, and affect of science education requires greater attention in the future.

Studies of affect also present their own methodological conundrums. The ephemeral, fleeting and episodic nature of situated affect makes it challenging to quantify. Perhaps this is one reason why it is often absent from high profile discussions of school and pupil performance. It now seems like a cliché to say that the ways in which we measure learning influences how learning is both publically and privately conceived and valued. In science education, we have clearly been drawn more to some approaches in the study of affect rather than others. There is an open question of why personal psychological studies have been so appealing and seem so influential in policy and curriculum reforms. The politics of why and how we speak for science education is important.

There has been a sustained interest in a "theory of content" in science education. This is based largely on an assumption that particular content might be best taught and learned in particular ways and in particular social and environmental contexts and settings. Few would disagree that some science content is more provocative and once encountered can arouse intense reactions and equate to particular political allegiances. Other content can, of course, be much more anodyne, dry, and mundane, and this poses its own set of educational dilemmas. Over the past few decades, increasing attention has been placed on socio-scientific issues that are themselves now readily associated with heightened emotions (sometimes grief and loss with apocalyptic dimensions). Global warming and climate change is one such example. Other examples include nanotechnologies, genetically modified foods, and nuclear power and weaponry. Encountering science and technology in these areas raises axiomatic questions of affect and learning. To use a distinction drawn by Bruno Latour, encountering "matters of concern" is likely to be very different than encountering "matters of fact" – a distinction that raises some important pedagogical questions for science education. Traditionally, we have tended to associate difficult knowledge with conceptual demands rather than emotional demands. The emotive power of content still remains largely unexplored. More recently, Maria Puig de la Bellacasa has encouraged us to move beyond facts and concerns to reflect on "matters of care" in techno-science and ask: "Who cares?" "Why ought we care?" "How ought we care?" Reactions to climate change, for instance, raise questions of the importance of understanding the science involved but also, perhaps even more importantly, recognizing why, how, where, and with whom we should, or might, care. Although "pedagogies of care" have been a topic of sustained attention in education, they have yet to develop as a major theme of interest in science education and as such offer an intriguing topic for future research.

Recognizing the constitutive nature of cognition and affect (in contrast to more dualistic orientations) raises profound questions central to any considerations of science teaching and learning. As science educators, our pedagogies are at their heart an invitation to invite others into our worlds and experience a subject that has occupied our minds and emotions for such a long time. This invitation carries with it an open prospect of encountering the wonderment, delight, hopes, challenges, and possibilities of seeing the world and ourselves in different ways. Studies of affect hold the potential to simulate a new body of research with fresh insights into the teaching and learning of science. This can have far-reaching implications for practice and this seems even more pressing in an era of truly global concerns.

Cross-References

- ▶ Attitudes to Science and to Learning Science
- ▶ Attitudes Toward Science, Assessment of
- ▶ Emotion and the Teaching and Learning of Science
- ▶ Interests in Science
- ▶ Learning Science in Informal Contexts
- ▶ Situated Learning
- ▶ Socioscientific Issues

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After School Science

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Keywords

Afterschool; Diversity/equity; Hands-on learning; Informal science education; STEM education

Introduction

Nations all over the world are recognizing the importance of preparing their students to be literate and proficient in science, technology, engineering, and mathematics (STEM) fields so their citizens can navigate the modern world and participate productively in the workforce. For students in kindergarten through high school, the formal school day and classroom teachers are at the forefront of the effort not only to increase the number of children and youth who have access to STEM learning opportunities but to do so in an equitable manner that will reach and equip a diverse group representative of the nation's population. But because children spend less than 20 % of their waking hours in school, out of school-time experiences such as afterschool programs – and the institutions and people who provide them – need to be essential partners in this effort. Both the additional time offered by afterschool programs and the opportunity are needed to diversify the ways that students experience STEM learning.

"Afterschool" is defined here as programs which provide an array of safe, supervised, and structured activities for children and youth that are intentionally designed to encourage learning and social development outside of the typical school day. Programs generally operate during the hours immediately following school dismissal; however, they also include activities that occur before school, on weekends, over school breaks, and during the summer. They may be located at a school or off-site, but the programs that show more impact on the participants are usually aligned with the school day (Afterschool Alliance 2011). A common element across these programs is an engaging, hands-on learning approach and less formal environment that aims to feel different from school. Afterschool programs are different from some of the other informal science education (ISE) environments in that they are usually much more structured and sit at the junction of the school day and a truly free-choice learning environment.

In the United States, afterschool programs present a significant potential for young people to engage in STEM education programs – 8.5 million children participate in afterschool programs and structured, comprehensive afterschool programs provide an average of 14.5 hours of programming per week for the participants. Children from populations traditionally underrepresented in STEM fields are more likely to participate than others (Afterschool Alliance 2009) – 24 % of African-American, 21 % of Hispanic, and 16 % of Native American children attend afterschool programs, compared to the national average of 15 %. Girls attend afterschool programs in equal numbers to boys. The afterschool setting thus presents an opportunity to reach the very populations we need to bring into the STEM pipeline through experiences that supplement and complement the school day.

Why STEM in Afterschool?

Afterschool programs have traditionally been very strong on targeting and delivering youth development outcomes. Public support for this setting has also been traditionally based on keeping children and youth safe and providing them with enriching experiences that contribute to the development of the whole child. However, modern afterschool programs do much more than keep kids safe and are strong learning environments that provide a wide array of engaging activities. Many of them have embraced STEM programming and pride themselves on providing engaging hands-on learning opportunities that complement the school day and get young people excited and knowledgeable about STEM topics and careers.

National youth organizations in the United States such as 4-H, Girls Inc., and Girl Scouts and a few other strong state and local afterschool providers have been offering STEM education programs for many decades. However, over just the past 5 years, the general afterschool field has come to enthusiastically embrace STEM programming and is deepening its commitment to offering STEM learning opportunities. Afterschool programs are strategic partners to engage in STEM education – they provide an environment that is free of many of the constraints of the school day and is structured yet flexible. Children and youth can engage in STEM learning and projects in this setting without fear of academic failure. Afterschool programs are characterized by a focus on project-based learning, relevance to real life, and exposure to STEM career options. Thus young people in these programs can meet and interact with adults working in STEM fields; be encouraged to appreciate the relevance of STEM topics and fields to their daily lives and global problems through hands-on projects; and come to understand that persistence in the face of failure is crucial for being an effective STEM professional. It is also a setting where technology and engineering education can occur as they are often not included in school curricula.

Among students who are fortunate enough to have access to afterschool enrichment opportunities, the benefits of afterschool programs in general are well documented, showing positive impacts on both academic and behavioral development. A review of evaluations of afterschool programs in 2011 showed that attending high-quality STEM afterschool programs yields STEM-specific benefits that can be organized under three broad categories: improved attitudes toward STEM fields and careers, increased STEM knowledge and skills, and higher likelihood of graduating high school and pursuing a STEM career.

Supporting STEM in Afterschool

The US Department of Education’s 21st Century Community Learning Centers program is the largest exclusive federal funding stream for afterschool programs (at approximately $1B as of 2013), but many other federal agencies also allocate small pots of funds for supporting various aspects of afterschool programming. While only a small portion of these public monies are applied toward afterschool STEM programming, corporate and philanthropic foundations have recognized the potential of this space for STEM education and have begun investing in it as well.

To enable growth and support for STEM in afterschool, infrastructure is being assembled at a rapid pace. In addition to supports and technical assistance that go along with federal funding streams, system-level intermediaries funded by private philanthropic foundations are working to increase the quality and availability of afterschool programs and STEM learning opportunities within such programs.

Statewide Afterschool Networks operating in 42 states (as of 2013) are increasingly becoming the brokers to advocate for and coordinate afterschool STEM learning efforts in their states. Similarly, *Every Hour Counts* is a partnership of intermediary organizations dedicated to increasing the availability of high-quality afterschool programs by building citywide afterschool systems. Both these networks follow a model of advocating for policy changes at the state and local levels while working to build capacity at the practitioner level.

To aid with the capacity building and professional development needs, strategic partnerships are being formed to bridge the learning that happens within the traditional school day and in afterschool programs. Examples of systemic partnerships include those with school districts, science centers and museums, federal science agencies, and businesses and corporations. This type of alignment and reinforcement of learning will be especially critical as the nation moves toward adoption of a common set of national standards (the Next Generation Science Standards), which will require STEM education to go beyond content knowledge and embrace contextualized modes of learning.

Challenges

However, several challenges remain. Although afterschool programs are increasingly being recognized as important partners in STEM education, much of the dialogue about STEM education improvement centers around what traditional schools can do. The education reforms that are unfolding also mainly target the school day, and hence most public policy initiatives and public dollars target formal schooling as well. As children and youth spend less than 20% of their waking hours in school, it is critical that there is movement away from a model of placing the entire burden on schools and toward a model of a learning "ecosystem" that includes all relevant partners and has appropriate funding streams attached to it.

The range of STEM offerings in afterschool programs varies from one-off science activities to yearlong projects. Consequently the range of reported outcomes for afterschool STEM programs and the language used to describe them also vary greatly. There is a need to define an ISE outcome framework for afterschool that takes advantage of its strengths and clearly defines how it is responding to the national need around STEM education. A challenge for the field is to document and demonstrate the ways in which children's deepening STEM learning and engagement develops and is made possible (and possibly is more inclusive, including of children who do not succeed in school science) *because* of the strong youth development contexts in which the teaching and learning take place. That is, rather than choosing between youth development and STEM learning, it is imperative that the field identify ways of showing how they interrelate and indeed advance one another in the context of the broad reach and audience of the afterschool student population.

There have been efforts to define meaningful outcomes for ISE: the National Science Foundation released a *Framework for Evaluating Impacts of Informal Science Education Projects* in 2008 that defined impact categories (Friedman 2008); the National Research Council's 2009 report, *Learning Science in Informal Environments*, described six strands of science learning in informal environments (National Research Council 2009). Most recently, the Afterschool Alliance conducted a Delphi study (Afterschool Alliance 2013) that asked expert practitioners, policymakers, and funders to define an appropriate set of outcomes and indicators of learning for afterschool STEM. A challenge is how to take these studies and design assessments that do not change the social and cultural tenor of the afterschool space but reveal the ways in which the skills students are developing go hand in hand with the kinds of understandings traditionally associated with schools such as conceptual knowledge.

Afterschool programs have emerged as strong partners in STEM education improvement efforts. Policy initiatives and appropriate resource allocation would allow them to go the next step and become an essential part of the STEM learning ecology.

Cross-References

- ▶ Affect in Learning Science
- ▶ Learning in Play-Based Environments
- ▶ Learning Science in Informal Contexts

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Agency and Knowledge

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An Agentive and Social Conception of Knowledge

What is the meaning of knowledge? We think that any educational endeavor rests on a conception of what knowledge is. This conception may be explicit or tacit, but we argue that it shapes the way educational processes unfold and the conception in turn is shaped by these educational processes.

In this short entry, we propose an agentive conception of knowledge. What does it mean? We consider knowledge as a power of acting. In that conception, learning a piece of knowledge means becoming able to act in a specific new way. This definition does not imply any normative conception of knowledge. For example, a person who learns a science formula by rote and without understanding has gained a power of action. If someone asks her to recite this formula, she will be able to do it and she will be able to do something she was unable to do before she learned by rote. One may argue that that is a poor conception of science education, in that the learned capacity is not very strong. But it suffices to find an educative situation, in a given institution, in which “reciting” is the right thing to do, to convince oneself that, in this setting, the person who recites the formula accurately fulfills the local educational obligations. Of course, it will be possible to find educational settings in which knowing a formula only by rote will not be sufficient. One can even think of educational settings in which rote learning will not be necessary. But we claim that in each case, knowledge, as a power of action, is shaped by the institutional setting in which it is used.

This leads us to a definition of knowledge. Knowledge is a power of acting in a specific situation, within a given institution. This conception of knowledge is both agentive and social. It is agentive, in that it sees that knowledge through the possibilities of acting it enables human beings to undertake. It is social, in that it relates these possibilities of acting to the way the social structure in which knowledge is acquired considers them.

Transmission of Knowledge in Joint Action Theory in Didactics

Conceiving knowledge as a power of acting in a specific situation, within a given institution, gives us an ontology of knowledge, both social and agentive. But such a definition has to be worked out in order to be productive. In the Joint Action Theory in Didactics, the transmission of knowledge is conceived of as a knowledge building, which is viewed in a specific dialectic between two concepts of the theory, the contract and the milieu.

The relation between the teacher and the student is considered as a transaction in which the object is based on knowledge. In this transaction the teacher's intention is to teach knowledge and the student's intention is to learn knowledge, and a problem is at play. Here "problem" corresponds to what is at stake in the transaction and thus is not limited to its usual meaning.

The didactic contract can be seen as the previous knowledge system against the background of which the teacher and the student deal with the problem at play. This knowledge system has been developed in the prior joint actions between the teacher and the student. It is both epistemic (e.g., the way of resolving a given problem or a particular concept as it has been figured out in the didactic joint action) and transactional (grounded on a system of reciprocal expectations between the teacher and the student). The contract then can be seen as a system of rules structuring the didactic action and, more generally, as the strategic systems used by the teacher and the student to deal with the problem at play in the transaction.

The didactic milieu (Sensevy 2012) is the actual material and symbolic structure of the problem at play, which the teacher and the student have to deal with in order to solve this problem. At the outset of the interaction, most of time, the milieu is not identical for the teacher and the student, depending on their understanding of the problem. The milieu can be described as the set of symbolic forms that the didactic experience transforms in an epistemic system, through the didactic contract.

In this perspective, what we call didactic equilibration refers to the way contract and milieu are related in the didactic activity. One can delineate two main patterns of didactic equilibration. According to the first pattern, the milieu is used by the teacher mainly as a way of reenacting a piece of knowledge already encountered by the student. We termed this structure a contract-driven equilibration. According to the second pattern, the contract is used by the teacher as a way of organizing the student's inquiry in the milieu so that he/she is able to solve the problem on his/her own. We term this structure a milieu-driven equilibration.

This theoretical conception enables us to come back to the issue of agency and knowledge. We assert that didactic activity has to be carried out in institutional settings in which the power of acting that the knowledge bestows is acquired through an equilibration form in which the conceptual priority is given to a milieu-driven equilibration. In that, the student's power of acting is strongly related to the teacher's capacity to enable the student to use accurately the didactic contract meanings and to accept to work in a certain kind of epistemic uncertainty to explore the milieu. The result of this equilibration work will be the growing of the student's epistemic agency.

Let us give a short example of such an epistemic agency.

An Example in Mechanics

The chosen example (Tiberghien et al. 2009) comes from a mechanics teaching sequence at high school level (grade 11) after the introduction of the inertia principle and Newton's first and second laws. One of the activities to carry out in small groups (two students) proposed the situation where a student, standing up on the ground, pushes horizontally on a vertical wall. The question was "By using the laws of mechanics, say if the forces that are exerted on the student compensate for each other or if they do not compensate for each other. Indicate the law(s) to which you refer to answer." To solve this problem the students had to make the experience, and they have an available text, given by the teacher during a previous session, with the laws of mechanics.

The two students working in group who were observed and videotaped showed two ways of seeing the situation and solving the problem; they instantaneously disagree and gave different arguments (A, the first student; L, the second student; T, the teacher):

1. A: no.
2. L: yes.
1. A: no because you do not feel the force of the ground but you feel the force of the wall.
2. L: but look at me I am going to tell you something it is [L is looking for something in his file].
3. A: no you do not feel the force no.
1. L takes the sheet and read the Inertial principle. [. . .] L calls T and T arrives.
1. L (to T): in the inertia principle, there is a condition that says that if the velocity of the inertia center is null, then (. . .) the forces compensate for each other.
   T leaves the group [. . .]
2. L: in fact you are like that there is there is/last year we saw the inertia principle it was er the forces they compensate for each other either the object it did not move like here the forces compensate for each other or there is a uniform rectilinear motion then that is if the vector is constant that is in the same direction same length [. . .] (L reads and shows the statement with his finger) if the velocity of the inertia center of a system is a constant vector, then the sum of the forces exerted on the system is null; here the constant vector is null.
3. A: but it means that in fact all the forces there remains the force of the Earth only.
4. L: no even not/all the forces they canceled.
5. A: pouff wait I have to read the summary again (10s) indeed but I am not sure; I wonder if there is not a force that does not get canceled.

For the two students, the contract-milieu relations are not the same when solving the problem.

Student L looks for the text of the principles and uses it; his strategy starts by raising a physics principle; he then checks it with the teacher if he can apply it. Then, the starting point (the problem statement, the studied situation of pushing a wall that he experiences, etc.) of his inquiry strategy is elements of the milieu and his strategy development is based on the contract (text of the laws, calling the teacher, etc.). In this case the use of contract (as the knowledge system developed in the prior joint action between the teacher and the student) is motivated by the milieu that orients the contract. In other terms, the didactic equilibration process is milieu driven.

Student A uses his perception and puts in question the physics principle. His relationship with physics knowledge leads him to use his own perception as a solution more certain than a physics principle. Consequently he does not use the available elements of milieu. His strategy development is directly associated to what he personally knows, as a previous system of knowledge which would enable him to answer the question. In this case it is the contract that orients his activity. The didactic equilibration process is contract driven.

Concluding Remarks

This example enables us to underline a critical point. In our mind, epistemic agency is not a “here and now” achievement. Even though it can be acknowledged in a specific problem solving, this performance depends on a long-duration inquiry process, in which students are enabled to acquire a scientific thought style (Fleck 1981; Sensevy et al. 2008), that one may consider as an epistemic activity in which the current system of knowledge (the contract) has always to be redesigned by the elements of the problem at stake (the milieu). This long-time process needs a specific methodology to be documented (Tiberghien and Sensevy 2012).

Cross-References

- ▶ Communities of Practice
- ▶ Didactical Contract and the Teaching and Learning of Science
- ▶ Epistemic Goals
- ▶ Epistemology
- ▶ Milieu

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Alienation

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Characteristics

Alienation is as a sociopsychological construct broadly defined as the state of being/feeling disengaged, disempowered, and isolated from people and/or the local contexts where one is embedded (Lukes 1978; Calabrese 1987). Its symptoms are both individual and collective and are manifested in unique ways by those who have been positioned, or position themselves as, the Other. To be the Other is to be outside of an established norm, and being outside of an established norm results in the development of a bevy of emotions which result in "the distancing of people from experiencing a crystallized totality both in the social world and in the self" (Kalekin-Fishman 1998, p. 6).

In science education, where teaching is often focused on the meeting of arbitrary benchmarks of science skills, and learning is assessed based on the ability of the student to memorize information, alienation is one of the chief means through which a large number of youth underachieve in science. This is the case because school science lends itself to the creation of spaces where there are constant clashes between science, school science, and the ways of knowing and being of students in classrooms. In urban science education, where socioeconomically deprived urban youth of color populate classrooms, alienation from science is a pervasive issue. In these classrooms, alienation is closely correlated to Durkheim's term anomie, which he describes as a mismatch between individual/group norms and larger societal norms (Durkheim 1915).

In urban classrooms, larger societal norms reflect a White, middle-class experience (Bourdieu and Passeron 1977) that is markedly different from the experiences of urban youth. In urban science classrooms, "the dominant cultural ideals of mainstream White society and Eurocentric science…are incommensurable with the beliefs and values of African American students" (Seiler 2001). This incommensurability is exacerbated by the physical structures of school and science such as textbooks, scripted curriculum, and laboratories that do not reflect the culture of students. When textbooks do not have images of Black and Brown scientists, curriculum does not create a space for students to express their inherent need to question, and cultural dispositions that align to orality, impromptu expression, verve, and movement are not considered in the teaching of science, youth of color are alienated from the discipline just by entering into the classroom (Emdin 2010).

While the larger structures of traditional science classroom alienate urban youth just because they happen to be in those physical spaces, alienation is even more deeply expressed because of the constant efforts to extract/invalidate urban youth culture in teaching and assessments. For example, when students are given academic grades in science based partly on "good" behavior or "academic potential," they may be inadvertently judged based on the extent to which their expressions of culture are aligned to a Eurocentric ideal or the extent to which they are able to hide this culture. This process equates to an attempt to wipe out of the customs and the understandings of a population to the extent that consciousness of oneself within a context (in this case the science classroom) is a negating activity. In other words, they are commended or viewed as more scientific for not being themselves or for being closest to what is perceived to be a White male scientist ideal (Emdin 2011).

Finally, one cannot understand alienation without having some understanding of affiliation. Affiliation, which is the state of being connected to, or feeling the connections between, self and others, is a significant component of making youth feel like a part of the science classroom. It is also one of the major ways of being within communities who are not well represented in science. For these populations, there is strength in acknowledging their unique culture, and feelings of contentment, satisfaction, belonging, and togetherness are developed as they communicate with each other. Each of the emotions generated through affiliation stand in contrast to powerlessness, meaninglessness, normlessness, cultural estrangement, self-estrangement, and social isolation that Seeman (1959) suggests are the result of alienation. If youth develop these emotions within science classrooms, they will not see themselves as scientists.

Cross-References

- ▶ Acculturation
- ▶ Cultural Influences on Science Education
- ▶ Culture and Science Learning
- ▶ Emotion and the Teaching and Learning of Science
- ▶ Indigenous and Minority Teacher Education

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Alignment

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Keywords

Achieve methodology; Surveys of enacted curriculum methodology; Webb methodology

Alignment of Assessment

There are research studies which look into the alignment of assessment and instruction and assessment and content standards. These alignment studies provide data to guide decisions on assessment, standards, and instruction. Based on the findings of these alignment studies, decisions for changes can be made on course level, e.g., related to course content, course objectives, and assessment tasks. The data may also inform educators to make decisions to align instruction or the curriculum for targeted learning outcomes.

Different methods are employed to study alignment including Webb methodology, Achieve methodology, and Surveys of Enacted

Curriculum (SEC) methodology. These methods have all been adopted in the United States. Webb methodology was developed by Webb in 1997 when he compared alignment with content focus, articulation across grades and ages, equity and fairness, pedagogical applications, and systems applicability. Achieve methodology involves both qualitative and quantitative comparisons of assessment with standards. The SEC alignment methodology allows comparisons across schools, districts, or states.

Other methods to study alignment include eliciting assessment beliefs, observing assessment practices, and reflecting on assessment events. Having gathered these data, the researcher may subsequently compare the data collected relating to assessment with data relating to instruction or classroom teaching. There are studies which investigate alignment for vulnerable populations including students with disabilities, preschool children, individual students, and classroom teachers.

Cross-References

- ▶ Assessment Framework
- ▶ Assessment to Inform Science Education
- ▶ Assessment: An Overview

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Alternative Conceptions and Intuitions

- ▶ Alternative Conceptions and Intuitive Rules
- ▶ Alternative Conceptions/Frameworks/Misconceptions
- ▶ Alternative Conceptions and P-Prims
- ▶ Constructivism

Alternative Conceptions and Intuitive Rules

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Keywords

Conceptual change

A major thrust in science education research has been the study of students' conceptions and reasoning. Many have pointed out the persistence of misconceptions, naïve conceptions, alternative conceptions, intuitive conceptions, and preconceptions. Studies have covered a wide range of subject areas in physics, in chemistry, and in biology (Thijs and van den Berg 1995).

In view of the large volume of documented instances of alternative conceptions and reasoning, a theoretical framework with explanatory and predictive power seemed to be in order. While most of the previously mentioned studies adapted a content-oriented perspective of alternative conceptions, another approach is suggested by the intuitive rules theory. The intuitive rules theory takes a task-oriented standpoint, addressing the impact of specific task characteristics on learners' responses to scientific tasks (Stavy and Tirosh 2000). The main claim of this theory is that students tend to provide similar, intuitive responses to various scientific and daily tasks that share some external features. The intuitive rules theory offers four major intuitive rules. Two of these rules (*more A–more B*; and *same A–same B*) are identified in students' reactions to comparison tasks, and two (*Everything can be divided* and *Everything comes to an end*) are manifested in students' responses to processes of successive division. Here we refer briefly to the two comparison rules, whose impact can be seen in students' responses to a wide variety of situations.

Responses of the type *more A–more B* are observed in many comparison tasks, including classic Piagetian conservation tasks (e.g., conservation of weight, volume, matter), tasks related to intensive quantities (density, temperature, concentration), and other tasks (e.g., free fall). In all these tasks, relationships between two objects (or two systems) that differ in a salient quantity A are described ($A_1 > A_2$). The student is then asked to compare the two objects (or systems) with respect to another quantity, B ($B_1 = B_2$ or $B_1 < B_2$). It was observed that a substantial number of students responded incorrectly according to the rule *more A* (the salient quantity)–*more B* (the quantity in question), claiming that $B_1 > B_2$. We suggest that students' responses are determined by the specific, external characteristics of the task, which activate the intuitive rule *more A–More B*. This tendency is evident in a wide range of ages. For instance, even university students tend to incorrectly predict that a heavy box will hit the ground before a light one. This response is in line with the intuitive rule *more A* (heavier)–*more B* (faster).

Responses of the type "*same A–same B*" are observed in many comparison tasks. In all of them the two objects or systems to be compared are equal in respect to one quantity A ($A_1 = A_1$) and this equality is salient. Yet, these objects or systems differ in another quantity B (B_1 is not equal to B_2). A common incorrect response to these tasks, regardless of the content domain, is $B_1 = B_1$ because $A_1 = A_1$. Megged (in Stavy and Tirosh 2000), for instance, found that when middle school students were presented with two vials containing equal amounts of water and one of these vials was heated, the students tended to incorrectly claim that *same A* (water)–*same B* (volume of water).

The intuitive rules, which account for many incorrect responses to science tasks, have a predictive power. That is, one could predict how a student will respond to a given task on the basis of external, specific features of the task and a small number of intuitive rules. Moreover, the rules seem to be universal to affect students' responses regardless of culture.

Various instructional methods have been employed in science education for overcoming intuitive interference including teaching by analogy, conflict teaching, calling attention to relevant variables, raising students' awareness of the role of intuition in their thinking processes, and experiencing practical activities. Recently, cognitive psychology (e.g., reaction time) and neuroscience methodologies (e.g., fMRI) are employed to study the reasoning mechanisms related to intuitive rules (Stavy et al. 2006). The insight to be gained from employing these methods could lead to a deeper understanding of students' difficulties and their reasoning processes and eventually to improve science education.

Cross-References

- ▶ Alternative Conceptions and P-Prims
- ▶ Alternative Conceptions/Frameworks/Misconceptions

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Alternative Conceptions and P-Prims

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Keywords

Conceptual change

Setting the Scene

The discovery of students' alternative conceptions constitutes one of the major landmarks of science education. No longer is it sufficient to study only "effective methods," or general learning processes. Instead, the field came to understand that students had particular and resilient ideas about various scientific domains, which strongly affect learning.

Few doubt this constructivist presumption today. However, there is still much debate about how to construe these phenomena. As a result, there is also debate concerning how one should best pursue good instruction in the light of alternative conceptions. P-prims theory offers a carefully articulated and systematic approach to understanding the nature of students' naïve ideas, their origins, and their role in coming to understand science concepts deeply.

P-prims theory is part of a broader approach, called "Knowledge in Pieces" (KiP), to understanding the nature of students' intuitive ideas and their role in learning. P-prims theory deals with intuitive preconceptions per se, and other parts of KiP (e.g., the "coordination class" model) deal with the nature of expert concepts. Kindred approaches to KiP include Minstell's "facets" and Linn's "knowledge integration." Here, I use "the theory theory" and the basic idea of "misconceptions" to represent competing perspectives.

The Basic Idea

P-prims theory aims to explain student alternative conceptions as stemming from bits of intuitive knowledge that contribute to our intuitive "sense of mechanism," that is, what kinds of occurrences are natural and to be expected. P-prims express regularities, like scientific principles, except that there are many more p-prims than scientific principles, and there are other significant differences, described below.

"P-prim" stands for "phenomenological primitive." "Phenomenological" means that p-prims are usually evident in our everyday experience. One just sees situations in terms of them. As a consequence, what happens in a situation is regarded as natural if a p-prim applies, or surprising otherwise. "Phenomenological" also suggests that p-prims are encoded in ways other than in words, as images or kinesthetic schemes. "Primitive" means to imply that people cannot, in general, analyze or justify their p-prims. Part of this follows from the fact that they are not encoded in language. In contrast, the words "force equals mass times acceleration" provides a clear top-level analysis of Newton's laws, but the same cannot be done for p-prims (except by us, as analysts). Similarly, while Newton's laws can be argued for, explained, and even supported by empirical results, one cannot do those things for p-prims. P-prims are simply evoked by situations either directly or as a result of deliberately attending to other aspects of a surprising situation that might render it more comprehensible than our first impressions.

I will not discuss other aspects of p-prims theory, such as (1) how we describe a p-prim's contextuality – when it applies and when it does not – and (2) how they develop, as a result of sorting experience toward deeper principles.

P-prims theory maintains that there are hundreds or thousands of p-prims. That is, our personal search for ultimate explanation of the world does not result in only a few general principles. No p-prims are as deep and complicated as Newton's laws. So, we simply must have many of them to "cover" the array of experiences that we have.

In contrast to p-prims, the "theory theory" view maintains that intuitive knowledge comes down to just a few core principles. Some advocates of the theory theory even describe intuitive theories as "remarkably articulate," suggesting a close connection to language, which is explicitly denied by p-prims theory. The theory theory also contends that intuitive principles, in addition to being few, are substantially coherent. That is, they are embedded in a rich web of relations that mutually constrain all the pieces. P-prims theory maintains that p-prims, for the most part, have independent developmental histories and remain, at best, loosely interconnected.

Examples

Since there are many p-prims, there is no definitive list of them. However, we illustrate with some informative examples.

Ohm's P-Prim. Ohm's p-prim is one of the most powerful and important p-prims. It specifies that many causal situations can be understood as an "agent" acting against some kind of "resistance" to achieve some particular "result." People are prototypical agents that exert effort toward particular results. We "work harder" (e.g., push harder) in order to obtain greater result (which may be that an object moves either faster or farther). Various intervening "resistances," such as friction or the object's size, can moderate our efforts. Ohm's p-prim applies to intellectual effort, such as working harder to achieve a higher grade in school. In inanimate situations, agency may be attributed to elements of situations that have the capacity to make things happen. A rapidly moving object, for example, may be construed as an agent, or a battery might exert a kind of "effort" called "voltage."

In contrast to the misconceptions perspective, p-prims recognize the ecological validity of intuitive ideas. It is not strange that we have ideas that fit particular situations (throwing harder to have a ball travel faster). Such ideas are "entrenched" because they are excellent ideas. They simply work well for many situations in the real world. However, p-prims are not yet the complex, general, and articulated ideas of professional science.

P-prims research has found many reuses of intuitive ideas in learning science. Ohm's law in electricity is comprehensible to novices precisely because it is an obvious situation that is governed by Ohm's p-prim. Similarly, although Ohm's p-prim contradicts $F = ma$ in some situations, in other situations (e.g., those involving small objects moving through a viscous fluid, which involves Stokes' law friction) Ohm's p-prim is entirely consistent with Newton, and it is likely to be used for rapid reasoning, then, even by experts. The problem with Ohm's p-prim is not its incorrectness, but its vague contextuality. Students are prone to apply Ohm's p-prim where it should not apply, and they do not know that deeper principles can often replace and improve Ohm's p-prim even in circumstances where it does apply.

The fact of productive engagement of p-prims in learning science cannot be overemphasized. Misconceptions views uniformly characterize intuitive ideas as false and in need of replacement. Similarly, theory theory views uniformly describe naïve theories as in need of replacement. As a consequence, misconceptions and theory theory views are effectively "blank slate" theories of learning or, worse, views holding that the slate must be wiped clean before real scientific ideas can be developed. In contrast, p-prims theory sees many productive roles for p-prims, achieved through modifying them, adjusting their contextuality, combining them, and reorganizing them.

Abstract Balance and *Equilibration.* Balance is a powerful intuitive principle. When people view a balance scale, its behavior is intuitively comprehensible as a system that has a natural "balanced" position. According to the abstract balance p-prim, a balanced system can be disturbed and put "out of balance." If the disturbance is then removed, the system just returns to its natural state; it *equilibrates.* This conceptualization is a misconception to the extent that Newtonian mechanics requires a force or torque to drive equilibration; intuitively, return to balance just happens and needs no other explanation.

No putative naïve theories of physics recognize either abstract balance or other important balancing p-prims. Such ideas have been found particularly helpful, not surprisingly, in understanding thermal phenomena such as temperature equilibration. It is conjectured that balancing p-prims also help with understanding conservation laws, such as conservation of energy.

Carrying. One can easily imagine very young children recognizing that carried things just "go with" their carrier. A baby goes with the carrying parent. A toy in a child's red wagon just goes along wherever the wagon goes. A true physics explanation of these situations is simply too complicated for children, or even for most college students. So, the carrying p-prim is about as good an understanding of these situations as early physics learners can achieve.

Dropped Objects Fall. As with carrying, it is hard to imagine even very young children not noticing that when one drops an object, it falls (straight down). This p-prim, like others, fails as science because of contextuality. People do not notice that the "straight down" aspect only happens when the dropper is not moving. Yet, dropping from rest is so much more important and frequent in a young child's world that it should not be surprising that separate principles are not developed for moving drops.

Channeling, *Blocking.* The channeling p-prim recognizes that trains just follow their tracks and balls just follow along in a tube in which they move. Like equilibration of a balance scale, forces are not needed. Blocking is the very important phenomenon, observed every day, that sturdy objects simply support things put on them; they block falling. These situations are, again, somewhat complicated to analyze from a Newtonian point of view, so students often appeal to the relevant p-prims when asked about blocking or channeling situations.

Competitive Advantage

P-prims as a theory of intuitive knowledge have a number of advantages, compared to competitors. Here are a few:

Strong constructivism. Tracking the positive value of p-prims in learning science (Ohm's p-prim works for electrical circuits; balancing p-prims evolve into understanding conservation laws) distinguishes this view from the uniformly negative view of intuitive ideas in the misconceptions or theory theory views. So learning, when it happens, is easier to account for with p-prims.

Coverage. The theory view selects, without good rationale, the effects of certain p-prims (or combinations of p-prims) *in certain situations* (*not* where they work well) to "knight" as part of a "core theory," and it ignores many other p-prims. This is particularly problematic when naïvely less important p-prims grow substantially in importance when they enter into learning real science.

Tracking Learning at Fine Grain Sizes. The task of understanding how learning happens in sequences of student thinking is much easier to handle in p-prims theory. The theory theory marks one end of a wide spectrum as "the naïve theory," and the other as "the normative theory," but what happens in between requires more detail. P-prims' growing or fading in importance or combining with other ideas can track learning much more precisely. Recent p-prims work has been particularly rich in tracking moment-by-moment learning.

Implications for Learning and Instruction

Here is a short list of implications of p-prims theory concerning instruction, and some opportunities it may afford with future work:

Pools of Productive Resources. As we learn more about the p-prims students have, we come to understand better a pool of very helpful resources for instruction. Misconceptions or naïve theories that are "just wrong" cannot help us in this way.

A Fine-Grained Approach to Instructional Design. The latest p-prims work shows in detail how moment-by-moment learning can happen. As such, it is a lens that can be used to understand and refine instructional sequences.

Deep Learning Just Takes Time. The change from the naïve state to scientific understanding is unequivocally complicated when viewed at the grain size of p-prims. Recognizing this, many instructional approaches may simply be grandly overoptimistic. Experiments that try to squeeze down known-to-be-effective instruction to shorter interventions suggest that this may be impossible.

Learning in Many Contexts. P-prims are highly contextualized. It is almost certain that one cannot learn scientific ideas without sampling a wide range of contexts that employ the same scientific ideas, but are construed very differently from an intuitive point of view – and conversely!

Handling Diversity. The set of p-prims students may have and levels of confidence concerning particular ones may vary a lot from student to student. Recent p-prims-based work has allowed us to see these differences and to understand why they can lead to success or failure of instructional treatments.

Coaching Students Metaconceptually. A significant part of understanding the *nature of science* might well be understanding the distinctive properties of students' own intuitive knowledge and how it changes to become genuine science. It may be that this is far more important to students' learning than understanding "what scientists do."

Cross-References

- ▶ Alternative Conceptions and Intuitive Rules
- ▶ Alternative Conceptions/Frameworks/Misconceptions
- ▶ Computers as Learning Partners: Knowledge Integration
- ▶ Conceptual Change in Learning
- ▶ Constructivism
- ▶ Prior Knowledge

Further Reading

A full account of p-prims theory:
diSessa AA (1993) Toward an epistemology of physics. Cogn Instr 10(2–3):105–225
Contrasting p-prims with theory theories:
diSessa AA (2013) A bird's eye view of "pieces" vs. "coherence" controversy. In: Vosniadou S (ed) International handbook of research on conceptual change, 2nd edn. Routledge, New York, pp 31–48
Tracking moment-by-moment learning with p-prims:
diSessa AA (2014) The construction of causal schemes: learning mechanisms at the knowledge level. Cogn Sci (in press)
A p-prims account of learning through analogies; individual differences:
Kapon S, diSessa AA (2012) Reasoning through instructional analogies. Cogn Instr 30(3):261–310
A Knowledge in Pieces analysis of "misconceptions":
Smith JP, diSessa AA, Roschelle J (1993) Misconceptions reconceived: a constructivist analysis of knowledge in transition. J Learn Sci 3(2):115–163

Alternative Conceptions/Frameworks/Misconceptions

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Keywords

Alternative conceptions; Alternative conceptions movement; Alternative conceptual frameworks; Alternative frameworks; Implicit knowledge elements; Intuitive theories; Knowledge in pieces; Misconceptions; Personal constructivism; P-prims; Preconceptions; Cognition; Conceptual change

There are a great many studies into learners' ideas in science topics, focusing on learners at different levels of the education system (Duit 2009; Taber 2009). These studies reveal that learners often present ideas relating to science topics which are at odds with the target knowledge set out in the curriculum. These ideas have been described using a wide range of terms, including misconceptions, preconceptions, alternative conceptions, alternative frameworks, alternative conceptual frameworks, intuitive theories, and mini-theories. Sometimes particular authors distinguish between meanings for some of these terms, but usage varies across the literature so often the different labels are, in effect, broad synonyms (Taber 2014).

Interest in students' ideas came to prominence in science education in the 1980s when a considerable research program (sometimes labeled the "Alternative Conceptions Movement") developed around eliciting such ideas. The theoretical perspective that informed much of this work was personal constructivism, which considered knowledge to be developed iteratively within the minds of individual learners (Driver 1989; Gilbert and Watts 1983). Teachers were seen as being able to support and scaffold learning, but learning itself was considered an act of personal construction of knowledge. From this perspective, the notion (inherent in much discourse around teaching) that knowledge could somehow be “transferred” or copied from teachers and textbooks to learners in a straightforward way is untenable. The learners’ prior knowledge and beliefs were recognized as providing the conceptual resources for interpreting teaching, and studies showed that students commonly held informal ideas about science concepts and topics that were inconsistent with the target knowledge set out in the curriculum.

The constructivist perspective was influenced by a range of thinkers including Jean Piaget, George Kelly, David Ausubel, Jerome Bruner, and Lev Vygotsky. The personal constructivist perspective and the research programs it informed have been significantly criticized from various standpoints, although robust defenses against these different criticisms have also been offered, and the constructivist perspective continues to be widely adopted in science education (Taber 2009). However, it has become clear that it is important to distinguish between constructivism as a theory of learning (which is widely accepted) and constructivism as a wider epistemological stance (which is sometimes characterized as inconsistent with the epistemology of science). Those adopting a personal constructivist perspective have had to acknowledge an increasing focus on the importance of cultural and social influences on learning, with some commentators seeing social constructivist perspectives as contrary to (rather than complementary with or able to be accommodated within) personal constructivism.

The initial motivation for research in this area was the claim that students commonly held alternative ideas inconsistent with the science to be learned that were tenacious and which would impede the learning of canonical scientific concepts. It was widely argued that it was important to diagnose learners’ alternative conceptions in a topic before teaching and then to explicitly challenge them. Ideally learners would be presented with activities, demonstrations, and opportunities for dialogue that would allow them to recognize the superiority of the scientific concepts and models presented in the classroom to their own alternative conceptions. All aspects of this argument have been subject to criticism and counter claims. In particular, there have been debates about the key issues of the nature of learners’ ideas about scientific topics and the significance of alternative conceptions for subsequent learning.

Some initial characterizations of learners’ alternative conceptions were that these were of the form of personal theories to which learners were strongly committed. However, critics argued that learners’ ideas were more akin to “fragments” of knowledge, often of very limited ranges of application, and readily disregarded. Some argued that giving attention to “alternative conceptions” in teaching would seem to give them more status and was likely to reinforce rather than challenge them, whereas such ideas were otherwise likely to be readily abandoned when scientific knowledge was authoritatively and persuasively presented in teaching. The empirical evidence suggests that neither view is generally correct. The range of results reported in diverse studies suggests that learners’ ideas about scientific topics are actually quite diverse in nature, as might be expected when considered as knowledge “under development” (Taber 2009, 2014).

Some ideas have been found to be widely applied across broad ranges of application and to be retained despite teaching designed to explicitly challenge them. Two examples would be the idea that a moving object must be subject to a force (sometimes referred to as the impetus framework or F-v thinking), and the idea that chemical reactions occur so that atoms can fill up their outer electron shells (the octet alternative conceptual framework). These ideas seem to become well established, to be linked to explicit principles (and so can be seen to form the core of a framework of related conceptions), to be applied consistently and across diverse contexts, and to be largely retained despite teaching of the scientific models. These ideas have been reported across many different educational contexts.

However, not all of the reported alternative conceptions have these features, and some of the ideas reported in studies are more labile (as learners are not strongly committed to them) and do indeed seem to be better characterized as knowledge fragments. Clearly such characterizations are important in considering potential implications for teaching. Where students hold fanciful and weakly committed ideas about science topics, then these are likely to have limited influence on learning of target knowledge, and there is limited value in spending time devising teaching strategies that take them into account. However, it is known that an idea like the impetus framework is highly intuitive to many learners and often tends to be retained after school and even college instruction. Research also suggests that even when students learn to answer regular classroom exercises correctly from the scientific model, they may still apply their alternative intuitive ideas when facing a problem that cannot be solved by standard algorithmic approaches, or when asked a question set in an everyday context, or when facing real-life problems beyond the classroom.

Moreover, even apparently persuasive demonstrations that seem to convince students that their alternative conceptions are wrong may only dominate their thinking over short periods before they revert to their longer-established ways of thinking. For example, students who initially assume that current must decrease at each lamp in a series circuit are often found to change their minds once they have seen their predictions of lamp brightness and ammeter readings are wrong. However, after some weeks have passed the students are likely to revert to their original view and may actually "recall" the demonstration as having shown that lamp brightness or ammeter readings did indeed diminish around the circuit.

An important theme for research concerns the origins of students' alternative conceptions. A number of possibilities have been suggested, although in reality there will be interactions between these and many alternative conceptions cannot be understood to have a single distinct origin. One potential influence is genetic, in that our genetic inheritance provides the framework within which we can develop. Although it seems unlikely that specific ideas are coded in our genes, it does seem that we have genetically directed predispositions to perceive the world in particular ways. One well-known example is the ability of neonates to recognize faces (i.e., the general pattern of a face, not specific faces) suggesting this ability is innate. The ability to identify a face in what William James referred to as the "great blooming, buzzing confusion" a newborn baby experiences clearly has value but leads to people readily recognizing faces in all kinds of inappropriate places – so a vague resemblance to faces in images of the surfaces of the moon and mars is taken by some as evidence that aliens have deliberately sculptured faces there.

The importance of the cognitive apparatus responsible for recognizing familiar patterns in perception has been emphasized in an approach to thinking about students' ideas referred to as knowledge in pieces (Hammer 1996). In this approach (championed by Andrea diSessa and David Hammer among others), the importance of implicit knowledge elements not open to direct introspection is emphasized as the basis for intuitive understanding of the world. Certain patterns recognized as recurring in experience become so familiar that we come to see them as natural and part of how the world works. These implicit knowledge elements (sometimes called p-prims or phenomenological primitives) act as basic cognitive resources that are recruited to make sense of diverse phenomena. This processing is preconscious, so the individual is not aware of the p-prim, just the outcome of its application.

The knowledge in pieces perspective emphasizes how many ideas elicited from students which might be labeled as alternative conceptions may not be established ideas, but rather could be constructions undertaken in response to a researcher's questions offering a new (and perhaps transient) nexus drawing upon the more stable underlying knowledge elements. An example might be a research participant explaining the seasons in terms of the earth's distance from the sun, drawing upon a more general intuition that effects are greater closer to the source. However, even if many elicited conceptions begin in this way, once such conceptions are made explicit (e.g., verbalized or built into a mental image or simulation), they may often become incorporated into the individual's explicit knowledge base, i.e., coming to believe that summer is the time when the earth is closer to the sun in its orbit. The common alternative conception that objects will only continue to move when acted upon by a force does not match scientific understanding, but actually fits most people's experience of moving objects. Given its constant reinforcement in everyday life, it is not surprising that this has been found to be an especially tenacious alternative conception.

Although many of our formal conceptions of the world may begin as applications of intuitive knowledge elements (what Vygotsky called spontaneous conceptions), a key feature of human learning is the role of culture, and in particular language, that allows us to learn vicariously from the experiences of others. For such learning to be more than rote learning, it needs to be interpreted in terms of our existing stock of conceptual resources – with the inherent risk of misinterpretation. Nonetheless, formal learning of "academic" concepts allows us to learn vastly more than is possible if we relied on our spontaneous concepts alone. Unfortunately, many of the ideas with currency in popular discourse are themselves inconsistent with scientific concepts, and so "folk theories" may act as sources of individuals' alternative conceptions.

Language is the key mediator of meaning between individuals, although inevitably communication is imperfect. Sometimes language has been considered to influence the development of alternative conceptions such as when a technical term has associations from everyday life that do not match the scientific meaning (e.g., particles, electron spin), or when it is used metaphorically (plant "food") or is misleading (e.g., neutralization of an acid with a base does not always lead to a neutral product as students may assume is implied by the term).

Teaching may itself be the source of students' alternative conceptions. This may be either because students do not realize when such teaching devices as analogy, models, metaphors, and anthropomorphisms are being used to help make the unfamiliar familiar and so take these representations too literally or because alternative conceptions are taught. The common alternative conception about chemical reactions being driven by atoms seeking to fill their shells is clearly not based on students' direct experiences of atoms and therefore seems to be based on the interpretation of teaching which either presents inadequate models or offers ambiguous descriptions that students then misinterpret in terms of their intuitions of the world. Research has shown that some alternative conceptions in this particular topic area are found widely among trainee school teachers suggesting that some alternative conceptions are being directly taught to new generations of learners by their teachers.

Research to understand the nature and characteristics of students' conceptions continues because understanding the precise nature and status of different types of reported conceptions is important in understanding how conceptual change may be best brought about, e.g., by directly challenging student conceptions, by ignoring them and simply teaching the canonical ideas, or by seeing learners' conceptions as useful (or necessary) starting points that need to be modified over time through a multistage conceptual trajectory. Each of these approaches is likely to be most sensible in some cases and counterproductive in others. Research into implicit knowledge elements such as p-prims may even lead to strategies to recruit the most helpful intuitions in learning particular concepts. So where much early research on alternative conceptions was concerned with cataloguing the range of ideas presented by learners, current research in this area is closely linked to models of conceptual change and designing appropriate strategies for teaching different curriculum topics.

Cross-References

- ▶ Alternative Conceptions and Intuitive Rules
- ▶ Alternative Conceptions and P-Prims
- ▶ Ausubelian Theory of Learning
- ▶ Conceptual Change in Learning
- ▶ Constructivism
- ▶ Metaphors for Learning
- ▶ Piagetian Theory
- ▶ Prior Knowledge
- ▶ Scaffolding Learning
- ▶ Socio-Cultural Perspectives on Learning Science

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Analogies in Science

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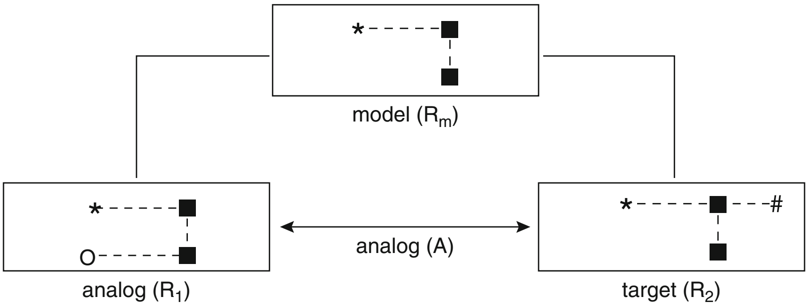
Keywords

Analog; Analogies; Scientists; Target

Analogies help scientists and everyday people make sense of the natural phenomena that surround them. We have an everyday object, event, or story that is well understood – this is called an analog, and a science concept to which it is compared called the target. Links – called mappings – are then made between the analog and the target. Mappings can be positive, ways in which the target is like the analog; negative, ways in which the target is not like the analog; and neutral, when it is not clear whether the target is or is not like the analog.

A visualization of mapping by Duit (1991) shows there may be identical features in parts of the analog (R1) and target (R2); the model (Rm) then represents similarity – with analogy (A) representing the relation between analog and target (Fig. 1).

To illustrate, we might compare a model of the atom with the solar system and map shared and unshared attributes: the sun and nucleus, the electrons and planets, and the sun is large – the nucleus is small, electrons travel much faster than planets.



Analogies in Science, Fig. 1 Duit's model for analogical transfer by mapping (This material is reproduced from Duit, R., 1991, Science Education, 75(6): p. 650, with permission of John Wiley & Sons, Inc)

The use of analogy works because it makes the unfamiliar (i.e., what we are trying to explain/teach) familiar by drawing on what the student already knows. We do need to make sure the analogy is interesting and familiar, and both the shared and unshared attributes need to be discussed. We also must point out where the analogy breaks down, lest students think the analog and target have things in common that they do not.

Cross-References

- ▶ Analogies, Metaphors, and Models
- ▶ Analogies, Role in Science Learning
- ▶ Analogies: Uses in Teaching
- ▶ Representations in Science

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Analogies, Metaphors, and Models

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Keywords

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It can be argued that all language is itself a metaphor, the "conduit metaphor" (Reddy 1979), such that meanings are contained in words and linguistic expressions are containers which are sent to somebody. A range of types of "containers" can be used. While a simile is merely a decorative addition to a statement, e.g., "as dead as a doornail," a metaphor is an attempt to understand something about which little is understood (the "primary subject") by considering it to be the same as something that is much better known (the "secondary subject"), e.g., "the sun (primary subject) is a furnace (secondary subject)." In so doing, the understanding of the secondary subject is also altered by an interaction of meaning: in this case it becomes possible to think of the furnace as life-giving.

The very readable book *Metaphors We Live By* (Lakoff and Johnson 1981) argues that metaphors are central to thinking and hence to communication, for they are the tools with which we conceive of, and hence experience, the world. They point out that metaphors can be grouped into categories, each of which is manifest with a particular resonance in a given culture. Typical categories are the "orientational," relating to positions in space relative to a person, e.g., "having full control of events is up" and "having no control is down," and the "ontological," where an abstraction is given the status of an object, e.g., "inflation is an entity." To be of any value, the characteristics of the secondary source must be known in detail. That said, a secondary source that is of great value is one that is drawn from a field of endeavor very different from that of the primary source. Metaphors do not identify exact equivalences; thus, there are attributes of a furnace that the sun does not have, e.g., a furnace uses oxygen, the sun does not. A metaphor seems promising where the secondary source has a number of important attributes that might be useful in understanding the primary source, and the relationship is explored to yield an analogy. In an analogy, the primary source is said to be like the secondary source to some extent, but not identical to it. The important issues are the identification of those attributes that are similar and the estimation of the degree of similarity.

Hesse (1966) separated the attributes of any secondary source into three types. Positive analogues are where some similarity seems likely, e.g., "the sun produces both heat and light as does a furnace"; negative analogues are where no similarity seems possible, e.g., "the thermal output of the sun cannot be controlled as can that of a furnace," while neutral analogues are attributes of the secondary source that may, or may not, be useful in understanding the primary source, e.g., “the sun may or may not consume its fuel.” Neutral analogues are valuable in that they direct research attention to the attributes in question. The conceptualization of the degree of similarity between a primary and a secondary source in respect of a given positive analogue is still taking place. “Structure mapping theory” (Gentner 1983) is a useful approach using an analogy of “distance” to discuss the issue. In it, a “near” analogy is one that is readily perceived, while a “far” analogue requires more adaption of ideas before the relationship becomes apparent.

The readiness with which metaphor and analogy can be used by an individual will depend both on the width of the spectrum of domains of knowledge with which they are acquainted in any detail and on their capability to evaluate the status and degree of similarity of attributes. These capabilities are manifest in the creation and use of models.

The world as experienced, as initially encountered, is a bewildering complex of objects and events. In order to make sense, to be able to think about it, humans (and probably other species) isolate and simplify specific aspects of it: models are produced. In the broadest sense, a model is therefore a simplified representation of any object, system of objects, events involving systems, or ideas about any of these, which is initially produced for a specific purpose. Mental models are ontological entities created in the mind and are vital to all thinking (Johnson-Laird 1983). Science, being centrally concerned with producing explanations of the world as experienced, places an especial value on models, for these are used to produce the predictions which are a defining aspect of scientific methodology. The creation of all models involves the identification of metaphors and hence on the drawing of analogies; being human creations, a distinct culture has evolved around them.

It is in the nature of science that once a mental model has been created in the mind of an individual, an attempt is made to express it to others. This expression can be carried out using gestures, materials, words, visuals (e.g., in pictures, diagrams, or graphs), symbols and equations, or a combination of these (Gilbert et al. 2000). It does seem that the translation in both directions between a mental model and an associated expressed model can involve some change: perfect communication is probably impossible. Each of these modes of representation relates to a given mental model in a precise way: each has a specific code of representational capability. Attempts to comprehensively communicate any mental model may therefore require the use of several modes of representation.

A mental model is expressed into the public arena by the creator(s) as a suggestion about the nature, structure, and mechanisms of the world as experienced. This suggested model is then subjected to tests by the science community and is then either discarded, amended, or accepted as a consensus model of some value. This valuation may continue for any number of years, ranging from a few (e.g., Pauling’s triple strand model for DNA) to very many (Aristotle’s model for motion). Eventually, in most cases, a given model is superseded for research purposes but is retained as an historical model because of its capability to provide adequate explanations of some phenomena that are now seen to be unproblematic. Metaphors, analogies, and models play key roles in science. Examples are Harvey’s metaphor of “the heart is a pump,” based on extensive knowledge of water pumps in mines, and Bohr’s metaphor of “the atom is a planetary system,” based on the standard model of the solar system, both of which advanced thinking considerably in their respective fields when they were proposed. The central role of science education of introducing students to science ensures that the major models produced by science are taught. These are usually historical models, originally proposed in a simplified form, and, having come to rest in the school curriculum, dwell there unchallenged for many years. For models that are particularly intellectually challenging, teaching models, based on metaphors that will be more readily comprehended by students, are devised.

Finally, in addition to transmitting established models, teachers themselves develop metaphors, and hence analogies and models, of their work. For example, they may see themselves as "captains of a ship," "entertainers," "facilitators of learning," and "assessors of learning." Professional development can involve causing science teachers to reconsider the significance of their chosen metaphor(s) of teaching.

Cross-References

- ▶ Analogies in Science
- ▶ Analogies, Role in Science Learning
- ▶ Analogies: Uses in Teaching
- ▶ Scientific Language

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Analogies, Role in Science Learning

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Keywords

Analog; Analogies; Learning; Models; Representations; Target

Introduction

Science education research studies have shown that analogies, when well designed, can support students' science learning. Well-designed science analogies can help students build conceptual bridges between what they already know and what they are setting out to learn. This entry explains what analogies are, how analogies support learning, and what form analogies should take to be effective. A research-based model for designing effective analogies is described: It provides guidelines for the use of analogies in science classrooms, textbooks, software programs, and Internet sites.

Science Education and Analogies

Analogies have often played an important role in scientific discoveries, not as proof, but as inspiration. Analogies have also played an important role in explaining those discoveries. Ernest Rutherford, for example, used an analogy when describing his experiment which led to the modern model of the nuclear atom. Rutherford had bombarded a metal foil with charged particles, and some of them bounced back. Rutherford said: "It was almost as incredible as if you fired a 15-in. shell at a piece of tissue paper and it came back and hit you.... I had the idea of an atom with a minute massive center, carrying a charge."

Science teachers, like scientists, frequently use analogies to explain concepts to students. The analogies serve as initial models, or simple representations, of science concepts. The teachers frequently preface their explanations with expressions, such as, "It's just like," "Just as," "Similarly," and "Likewise." These expressions are all ways of saying to students, "Let me give you an analogy." The students use these analogies to support their learning, and they often construct their own analogies. Constructing their own analogies helps students to take an active role in their learning.

Analogies are double-edged swords: They can foster understanding, but they can also lead to misconceptions. Effective analogy use fosters understanding and avoids misconceptions (Duit et al. 2001). In order to use analogies effectively, it is important to understand what analogies are, how they can support learning, and what kind of analogies are particularly effective.

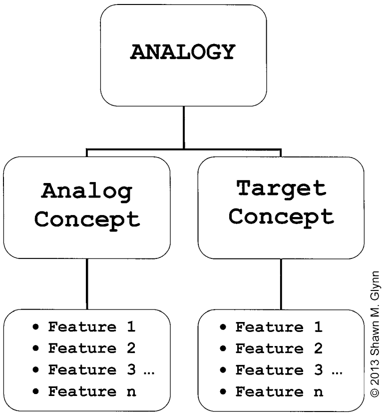
Analogy Defined

An analogy is a comparison of the similarities of two concepts. The more familiar concept is called the analog and the less familiar one the target. Both the analog and the target have features (also called attributes). If the analog and the target share similar features, an analogy can be drawn between them. A systematic comparison, verbally or visually, between the features of the analog and target is called a mapping. A conceptual representation of an analogy, with its constituent parts, appears in Fig. 1.

Analogical reasoning can occur between conceptual domains and within a conceptual domain. Between the domains of physics and biology, for example, an analogy can be drawn between a camera (with its lens, aperture, and microchip sensor) and the human eye (with its lens, pupil, and retina). Within the domain of physics, for example, an analogy can be drawn between a water system (with its pipes, pump, and pressure) and an electric circuit (with its wires, battery, and voltage).

How Analogies Support Science Learning

The analogies used in classrooms, textbooks, software programs, and Internet sites should be designed to promote elaboration, the cognitive process of constructing relations between what is already known and what is new. Elaboration can be activated by questions, objectives, personal examples, and other strategies, but analogies seem to be particularly appropriate because they can provide the rich, familiar contexts that successful elaboration requires. Elaboration is essential to ensure that students' science learning is meaningful rather than rote.



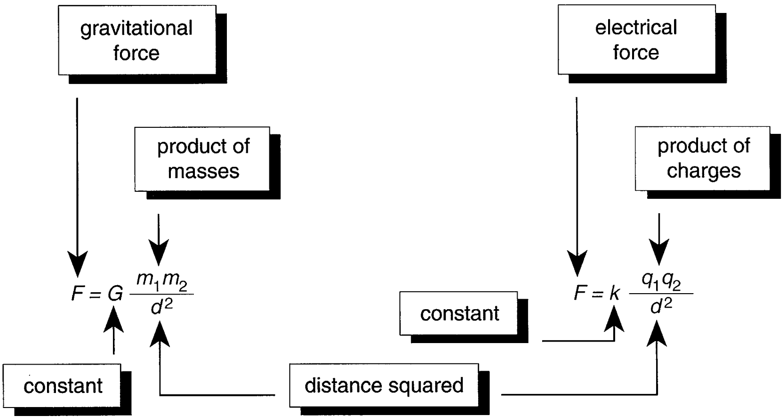
Analogies, Role in Science Learning, Fig. 1 A conceptual representation of an analogy

In a constructivist learning framework, students learn progressions of increasingly sophisticated mental models of science concepts. Often, these concepts represent complex, hard-to-visualize systems with interacting parts: An atom, a cell, photosynthesis, an electric circuit, and an ecosystem are all examples. Often, such concepts are introduced to students when they are about 10 years of age and then refined in subsequent grades, technical schools, and college. Familiar analogs (e.g., a factory) often serve as early mental models that students can use to form limited, but meaningful, understandings of complex target concepts (e.g., a cell). The analogy paves the way for the expansion of the target concept.

It is important to ensure that all students are familiar with the analog concept in order for it to be effective. Teachers should explain to students what an analogy is. Teachers should also encourage students to construct their own analogies and to keep in mind the limitations of analogies.

Highly Effective Science Analogies

In research studies, the effect of analogies has been inconsistent: Sometimes analogies increase learning and sometimes not. This inconsistency has been due to weak operational definitions of analogies, to constructions of analogies that have failed to map analog features systematically onto target



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Analogies, Role in Science Learning, Fig. 2 An analogy between two inverse-square laws: Newton's law of gravitation and Coulomb's law of electrical force

features, and to analogies that have not capitalized on visual imagery. Instructional analogies are sometimes limited to simple assertions, such as "Mitochondria are the powerhouses of the cell," without explaining the analogy. These assertions, or simple analogies, do not provide the instructional scaffolding that many learners need, particularly in the initial stages of learning a concept.

A much better mechanism for providing instructional scaffolding is an elaborate analogy: "In an elaborate analogy, analog features are systematically mapped onto target features, verbal and imagery processes are active, and these processes mutually support one another" (Glynn and Takahashi 1998, p. 1130). Elaborate analogies provide a rich, situated context for learning. By systematically mapping verbal and visual features of analog concepts onto those of target concepts, analogies can facilitate the cognitive process of elaboration. Elaborate analogies have been found to increase students' learning of target concepts and their interest in the concepts (Paris and Glynn 2004).

An Example of an Elaborate Analogy

Joseph Priestly was thinking analogically when he proposed a law of electrical force. Priestly was familiar with Newton's law of universal gravitation, which holds that the gravitational force between any two bodies is inversely proportional to the square of the distance between them. Priestly speculated, correctly as it turned out, that the electrical force between two charges is also inversely proportional to the square of their distance.

Charles Coulomb experimentally confirmed the law of electrical force, and the law was named after him. The analogy between Newton's law of universal gravitation and Coulomb's law of electrical force is mapped out in Fig. 2. In Newton's law, the gravitational force between two objects is proportional to the product of their masses and inversely proportional to the square of the distance between those two objects. Newton's law contains a constant, G, which is the universal gravitational constant.

In Coulomb's law, the electrical force between any two objects has a similar inverse-square relationship with distance. When objects or charged particles are small in relation to the distance between them, then the electrical force is proportional to the product of the charges and inversely proportional to the square of the distance between the charged particles. Coulomb's law also has a proportionality constant, k.

So, Newton's law of gravitation is analogous to Coulomb's law of electrical force. Both are inverse-square laws, and both have constants. But, although the laws are similar, there are important differences between them. For example, m represents the mass of an object, and q represents the charge of a particle. And, although both laws have constants, the G in Newton's law is a very small number, whereas the k in Coulomb's law is a very large number. Yet another difference is that gravitational force only attracts, while electrical force attracts when charges are different but repels when they are similar.

Teaching-With-Analogies Model

The Teaching-With-Analogies Model (Glynn 1995, 2007) is based on cognitive task analyses of how analogies are used effectively in lessons, textbooks, software, and Internet sites. In both formal experiments and classroom settings, the use of the model has been found to increase students' learning and interest in science concepts.

The Teaching-With-Analogies Model includes six steps. When applied to the analogy between Newton's law of gravitational force and Coulomb's law of electrical force, these steps are:

1. Introduce the target concept, Coulomb's law, to students.
2. Remind students of what they know of the analog concept, Newton's law.
3. Identify relevant features of Coulomb's and Newton's laws.
4. Connect (map) the similar features of the laws.
5. Indicate where the analogy between the laws breaks down.
6. Draw conclusions about the laws.

The analogy between the laws breaks down because the Newton's law G is a relatively small number and the Coulomb's law k is a relatively large number. This means that the gravitational force between, say, two 1-kg masses is tiny, whereas the electrical force between two 1-C charges is comparatively large. An important conclusion to draw is that gravity plays a more important role than electricity at planetary levels, but electricity plays a more important role than gravity at atomic and molecular levels.

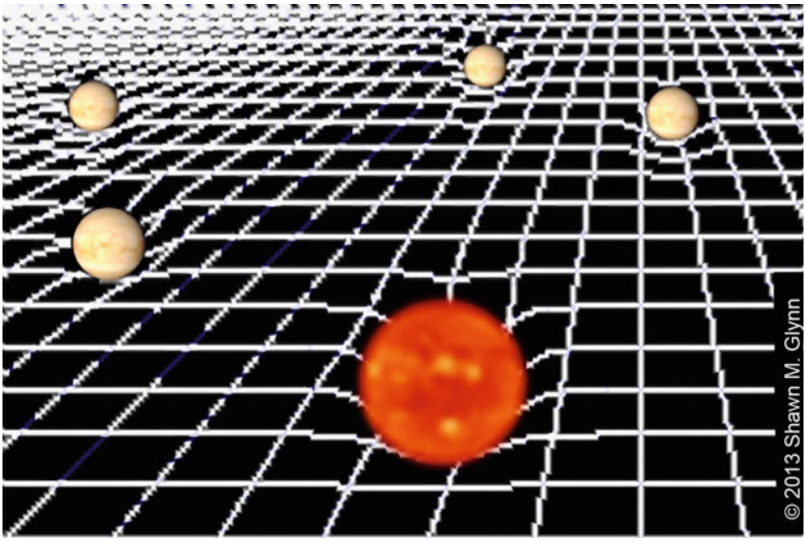
The Teaching-With-Analogies Model implies that teachers should try to select analogs that share many similar features with the target concept. In general, the more features shared, the better the analogy. Another implication is that teachers should verify that students have not formed misconceptions. One way to do this is to ask focused questions about features that are not shared between the analog and the target concept.

When teachers show students how to use the Teaching-With-Analogies Model, it becomes a Learning-With-Analogies Model (Glynn 1995, 2007), and the students can use its steps as guides when constructing analogies of their own (e.g., a heart is like a force pump, a kidney is like a waste filter, and a pulsar is like a lighthouse). Students are naturally inclined to generate analogies when learning science, but the analogies will be of higher quality if the students are taught how to systematically generate them. Sometimes these analogies are even more meaningful than those provided by teachers because the students draw on their own knowledge to construct them. Constructing analogies also helps students take a more independent approach to learning.

An analogy drawn between a concept covered earlier in a course (e.g., Newton's law of gravitational force) and one covered later (e.g., Coulomb's law of electrical force) is particularly effective because the earlier concept is familiar to every student. The previously discussed concept, however, should be reviewed to refresh students' memories.

An analogy can also foster students' transition to a new conceptualization of a previously taught concept. For example, as Newton conceptualized it, gravity is a linearly directed force: Objects with mass exert this attractive force. This conceptualization works well most of the time, and that is the reason it is still taught and frequently used. A better conceptualization, however, is that developed by Einstein: Gravity is a consequence of the shape of the universe. In this conceptualization, objects with mass alter the curvature of space-time, the 4-dimensional "fabric" of the universe. In Einstein's general theory of relativity, differential field equations describe how the shape of space-time depends on the amount of matter or energy in a region of space.

Because it is difficult to visualize 4-dimensional space-time, a 3-dimensional rubber sheet analogy is often used (see Fig. 3). Space-time is viewed as a sheet of rubber, stretched flat when there is no matter present.



Analogies, Role in Science Learning, Fig. 3 A rubber sheet analogy of space-time

If a massive object like a star is placed on this rubber sheet, the object pushes down into the sheet creating a cuplike depression. Less massive objects, like planets, create smaller depressions. An object like an asteroid traveling nearby the star would not pass the star in a straight line; the path would curve, as if the asteroid were rolling along the depression in the rubber sheet. If an asteroid were in the right position, going just the right speed, it might remain in the depression and orbit around the star.

The rubber sheet analogy helps students to draw important conclusions about space-time and Einstein's theory of general relativity. The curvature of space-time is responsible for gravity. Gravity is strong where space-time is curved and absent where it is flat. Although helpful in conceptualizing space-time, the rubber sheet analogy – like all analogies – breaks down. For example, the analogy is 3-dimensional rather than 4-dimensional, focusing on the spatial feature of space-time and ignoring the temporal feature.

Summary

Well-designed analogies are pedagogical tools that can support students' science learning. The steps in the Teaching-With-Analogies Model describe how to design effective analogies for use in classrooms, textbooks, software programs, and Internet sites. Well-designed analogies can help students understand many kinds of science concepts, including those with hard-to-visualize systems of interacting parts.

Cross-References

- ▶ Analogies in Science
- ▶ Analogies, Metaphors, and Models
- ▶ Analogies: Uses in Teaching
- ▶ Discussion and Science Learning
- ▶ Role-Plays and Drama in Science Learning

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Analogies: Uses in Teaching

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Keywords

Analog; Analogies; Science representations; Teaching

Externalizing Internal Mental Representations

Over the past two decades, consistent research findings have shown that a variety of external representations used by science teachers, science teacher educators, and science education researchers can lead to successful student learning outcomes. These external representations include analogies, metaphors, and models and model-based learning which have the effect of helping teachers and students externalize their internal mental representations providing avenues for discussion and more focused learning (see for example, Aubusson et al. 2006; Khine and Saleh 2011). This short entry deals with analogies as one form of external representation that is introduced by science teachers and used effectively with both elementary and secondary students when they learn a variety of science concepts.

Need for a Guide to Help Science Teachers Use Analogies Effectively

In science lessons, both teachers and students generate analogies, and sometimes these work well and sometimes they do not. Research has shown that analogies require explanation and analysis if they are to effectively contribute to students' science learning. Consequently, if analogies are to be used most effectively by science teachers, then a carefully planned teaching strategy is required that makes the analogies relevant to as many students as possible. As the vast majority of science teachers have no formal training in the use of analogies, it is not surprising that analogies used in teaching and learning are less effective than they could be.

In working with a group of science teachers who were interested in improving their teaching with analogies, Treagust et al. (1998) initially used an existing analogy-teaching model which was modified and adopted by teachers who taught a grade 10 optics class on refraction. The findings from this optics study and other studies led to the development of an approach called the FAR guide for teaching science with analogies, the letters being the three phases of the teaching strategy – focus–action–reflection (Treagust et al. 1998). This instructional strategy was designed to help teachers maximize the benefits and minimize the constraints of analogies when they arise in classroom discourse or in textbooks.

In the **focus** phase from his or her experience, the teacher decides whether or not the (1) *concept* is difficult, unfamiliar, or abstract, (2) what ideas about the topic that the *students* already know, and (3) whether or not the *analog* to be used is familiar to the students.

In the **action** phase, the teacher presents the analogy by (1) discussing those features of the analog and the science concept that are *alike*, drawing similarities between them and then (2) discussing those aspects where the analog is *unlike* the science concept.

In the **reflection** phase, the teacher and students discuss the analogy and *conclude* whether or not the analogy was clear and useful or confusing. Finally, the teacher reflects on the effectiveness of the analogy and whether or not *improvements* to the analogy should be made in light of outcomes.

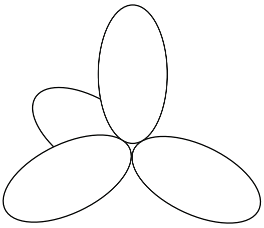
The phases of the FAR guide have become second nature to those teachers who become familiar with them, and these phases have been usefully applied to teaching and learning science concepts with analogies. A wide range of analogies for use in physics, chemistry, and biology lessons using the FAR guide is presented in Harrison and Coll (2008). One of these

49 analogies – balloon analogy for chemical bonds and molecular shapes – is presented below as a prototypical example.

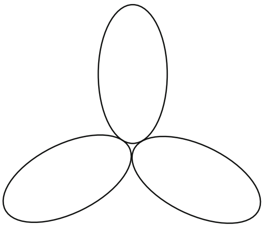
Balloon Analogy for Chemical Bonds and Molecular Shapes Using Focus–Action–Reflection (FAR Guide)

For this grade 11 chemistry lesson, the topic being taught is the forces between nuclei and electrons which result in the formation of covalent bonds that are electrostatic in nature. The repulsion forces between electron pairs around a central nucleus produce linear, trigonal planar, and tetrahedral molecules in, for example, ethyne, ethene, and methane, respectively. The teacher demonstrates the repulsion between adjacent electron pairs by means of four elliptical balloons inflated to their maximum with their stems tied together. The pneumatic pressure of four balloons forces them into a tetrahedral shape, and when one balloon is burst, the remaining three take up a trigonal planar shape. When a second balloon is burst, the two remaining become roughly linear (see Figs. 1, 2 and 3). Teachers can use this balloon model as an advance organizer for the lesson. This analogy works best once the valence shell electron pair repulsion (VSEPR) rules have been described which predict the shape of individual molecules based upon the extent of electron-pair electrostatic repulsion. Teachers typically use this demonstration along side other external representations such as space-filling and ball-and-stick models of molecules.

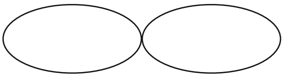
The FAR guide has been implemented with both secondary and elementary students. For example, Sickel and Friedrichsen (2012) engaged students (grade 9–12) in a predator–prey simulation to teach natural selection. The authors noted that, after using the FAR guide, classroom discussion was guided in a more purposeful way and that students had a more coherent understanding of biological processes and mechanisms. In a study with elementary students (grades 1–4) studying a variety of science topics, Smith and Abell (2008) noted that after implementing the FAR guide, teachers reported increased confidence and enthusiasm for teaching the topics and were more aware of the need for students to be familiar with the analog so that they could identify similarities and differences.



Analogies: Uses in Teaching, Fig. 1 Four balloons tied together form a tetrahedral shape



Analogies: Uses in Teaching, Fig. 2 Three balloons tied together (one is burst) form a planar shape



Analogies: Uses in Teaching, Fig. 3 Two balloons (another one burst) form a linear shape

Using Analogies to Engender Interest, Motivation and Conceptual Change

There is much potential for analogies to be used in the science classroom to not only improve conceptual understanding and engender conceptual change but also enhance student interest and motivation. Introducing analogies into science lessons and using them to achieve both conceptual and affective outcomes are consistent with many researchers who argue for a unity between the cognitive and emotional dimensions of learning. Similarly, children's and young people's thinking often involves visual imagery; by using their imagination, analogies used in the science classroom can create additional interest in the lessons. As noted above, researchers have reported that students enjoy lessons in which analogies were used to learn science concepts. Also teachers have exhibited enthusiasm and were animated when using analogies in their teaching. An excellent example of how analogies engender interest and motivation in science conceptualization is the interview with a student named Dana in the optics lessons reported by Harrison in Harrison and Coll (2008). Essentially, Dana's responses to questions about the optics lessons went from disinterested to enthusiastic and knowledgeable once the analogy was evoked. Thus, while the evidence is scant, there appears to be a prima facie case to investigate the relationship between learning and teaching with analogies and students' interest and enthusiasm for science.

Concluding Comments

The teachers who trialed this instructional strategy in their classrooms helped to refine the FAR guide to a point where it can enhance student understanding of the science concepts explained using analogies. Both teachers and researchers have reported viable learning outcomes with this approach. Provided teachers spend time negotiating each analog's familiarity and establishing the analogy's similarities and differences with their students, analogies can be powerful and motivating learning tools. The FAR guide does more than just establish analog familiarity and ensure valid shared and unshared mapping; it encourages teachers to regularly self-evaluate their teaching, and this should result in enhanced teaching and learning of science. Furthermore, when teachers use analogies effectively in their lessons, the opportunities for enhanced student interest and motivation are increased.

Cross-References

- ▶ Analogies in Science
- ▶ Analogies, Metaphors, and Models
- ▶ Analogies, Role in Science Learning
- ▶ Dilemmas of Science Teaching
- ▶ Evaluation of Textbooks: Approaches and Consequences
- ▶ Scientific Language

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Aquaria

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Introduction

An aquarium, or aquaria in plural form, is a site that offers visitors the chance to view water- and land-based animals (either marine or freshwater) in a museum-like environment; they include a variety of species including fish, amphibians, reptiles, and mammals; they include tanks, hands-on exhibits, interactives, educational programs, and sometimes touch experiences. Much of a person's learning during their lifetime happens outside of formal learning environments such as schools and universities, as documented by the National Research Council (USA) in

Learning Science in Informal Environments: People, Places, and Pursuits. Free-choice learning at places like museums, zoos, and aquariums is learning that is self-motivated, lifelong, and personally guided by an individual's personal needs and interests. While the exact definition of a public aquarium can be debated, it is estimated there are somewhere between 125 and 150 public aquaria worldwide; around 75 of these are in the United States alone (source: Wikipedia, "public aquarium").

History and Educational Opportunities in Aquaria

While people have kept fish indoors and on display dating back to the Roman Empire, public aquaria are roughly 150 years old starting with the first public aquarium opening in the London Zoo in 1853. The Association of Zoos and Aquariums (AZA) estimates that the 225 aquaria and zoos accredited by AZA account for more than 175 million visits worldwide; the largest aquaria attract more than two million visitors a year. Much of what motivates people to visit these institutions is viewing live animals they would not normally get to see, and this offers a unique opportunity for aquaria to connect and engage with visitors through exhibits, programs, and live animal "touch" experiences and increasingly through web- and mobile-based experiences.

Learning in Aquaria

Most public aquaria consider themselves to be informal science learning institutions and have education departments that work with local school groups or whole education systems, providing materials before, during, or after field trips to complement and enhance the visit itself. The learning that occurs during field trips typically focuses on cognitive information tied directly to the school curricula for that particular grade. However, the majority of aquaria visitors come outside of field trips, and learning for these visitors tends to be more open-ended, visitor driven, and more of a combination of cognitive, affective, social, and other types of learning than exclusively cognitive learning. In fact, visitor learning is influenced most by individual visitors' interests, prior experiences, knowledge, and motivations for visiting. Regardless of who someone is, what visitors learn in aquaria tends to be focused on the animals, although visitors often learn about the animals' habitats and human impact on animals and the ocean.

Learning About Conservation-Related Issues

In the past decade, there has been a noticeable shift from zoos and aquaria exhibiting animals to including messages about conserving animals and their habitats; including conservation messages is now common in institutional mission statements. As a result, research is being conducted about how a visit impacts visitors' conservation-related attitudes, beliefs, and behaviors (Yalowitz 2004). Recent studies have looked at the cumulative impact of visits across aquaria and zoo visits, including the *Why Zoos and Aquariums Matter* study (Falk et al. 2007), finding that aquaria and zoo visitors bring a higher-than-expected knowledge about basic ecological concepts, experience a stronger connection to nature as a result of their visit, have their values and attitudes reinforced, are prompted to reconsider their role in environmental problems, and can see themselves as part of the solution. While this is good news to aquaria and zoos, the *Assessing Public Awareness, Attitudes, and Actions: America and the Ocean* study found that the public still had only a marginal understanding of how oceans work, their relative importance, and the challenges we face in keeping oceans healthy. However, this study found that certain audiences, like teens and "tweens" aged 10–12 years, had a higher level of awareness about ocean-related issues compared to adults.

Learning About Climate Change

Studies at informal science education venues have shown that science-based institutions such as aquaria have visitors who are more aware of and knowledgeable about climate change compared to the general public. A supplemental round of funding by the National Oceanic and Atmospheric Administration (NOAA) in 2009 specifically supported aquaria and zoos communicating about climate change; one project is designed to build a shared community where zoos and aquariums can share information about interpreting climate change (see www.climateinterpreter.org). Aquaria are also starting to categorize visitors based on the well-known Global Warming's Six Americas Study to gauge whether aquarium visitors have different attitudes from the general public regarding climate change. One recently released publication discusses recent approaches and research for specifically communicating climate change in zoos and aquariums (Grajal and Goldman 2012).

Summary

In summary, aquaria have had a long history first as attractions and then as educational institutions who can effectively communicate science content about animals and their place in the world. As aquaria make the shift to stressing the importance of protecting animals, their habitats, and encouraging environmental stewardship, they have great potential to not only communicate science concepts and issues but empower visitors to take care of the world in which they live.

Links

Association of Science and Technology Centers (ASTC) – represents science-based visitor-based organizations, such as science museums, science centers, natural history museums, zoos, aquaria, and the like.

Association of Zoos and Aquariums (AZA) – international association representing zoos and aquaria, with a particular focus on education.

ClimateInterpreter.org – a site for the zoo and aquarium community to share about how to most effectively communicate climate change to the public.

Informalscience.org – a repository of evaluation and research reports, many focusing on learning and education; one can search evaluation reports by "aquarium."

NOAA Ocean Education Grants for AZA Aquariums: FY09 – a series of grants "to support education projects designed to engage the public in activities that increase ocean and/or climate literacy and the adoption of a stewardship ethic."

The Ocean Project (TOP) – a nonprofit that "advances ocean conservation in partnership with zoos, aquariums, and museums around the world."

Cross-References

- ▶ Excursions
- ▶ Visitor Studies

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Argumentation

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Keywords

Argument; Argumentation analysis; Argumentation layout; Reasoning

Argumentation in Science Education

Argumentation may be conceptualized in a range of ways, at least two of which are relevant for science education: first, argumentation as justification, or the evaluation of knowledge claims in the light of available evidence, and, second, argumentation as persuasion of an audience (Erduran and Jiménez-Aleixandre 2008). Argumentation plays a central role in the building of explanations, models, and theories, as scientists use arguments to relate the evidence they select to justify the claims they reach through use of warrants (Toulmin 1958). In science education, argumentation studies can be framed in two complementary approaches: on the one hand a theoretical approach – grounded in epistemology – about appropriation of scientific practices, that is, epistemic practices associated with producing, communicating, and evaluating knowledge in science, and on the other hand a policy approach (central, for instance, to the Program for Indicators of Student Assessment, PISA) emphasizing the development of scientific competences, in particular the ability of using scientific evidence to draw and communicate conclusions and of identifying the assumptions, evidence, and reasoning behind conclusions. The rationales for argumentation in science education draw also from other fields, such as language sciences, psychology, and science studies. Rather than being a one-way relationship, argumentation studies and science education have the potential to inform these perspectives, leading to fruitful interactions.

It is not easy to disentangle the influences of these fields, as sometimes they are combined, as happens with science studies, highlighting the importance of discourse in the construction of scientific knowledge, and language studies. Not all linguistic interactions should be considered as argumentative, but only those concerning the process of contrasting two or more views or meanings and of negotiating a solution. From discursive interactions, the ones that can be regarded as argumentative are those involving, for instance, formulating claims, supporting them with evidence, or evaluating arguments. On the other hand, argumentation in science education is not just a linguistic activity, but requires drawing from the relevant knowledge, selecting appropriate sources, and analyzing it by means of particular skills. Developmental psychology has examined, for instance, the epistemological and cognitive prerequisites for engaging in argumentation. A developmental pattern of epistemic cognition is reviewed by Garcia-Mila and Andersen (in Erduran and Jiménez-Aleixandre 2008). There is also a perspective viewing argumentation as a psychosocial practice embedded in institutional, historical, and cultural contexts (Muller-Mirza and Perret-Clermont 2009), a view combining developmental, social, and sociocultural approaches.

A key feature of argumentation, according to Osborne, MacPherson, Patterson, and Szu (in Khine 2012), is the role of criticism in the construction of knowledge. The implication would be that learners should be provided with opportunities to engage in critique and evaluation. About the contributions of argumentation to science learning, Tiberghien (in Erduran and Jiménez-Aleixandre 2008) summarizes the place of argumentation in science education in terms of three goals: acquiring knowledge about nature of science, developing citizenship, and developing higher-order thinking skills.

Jiménez-Aleixandre and Erduran (in Erduran and Jiménez-Aleixandre 2008) propose that argumentation may support the following: (a) the access to the cognitive and metacognitive processes characterizing expert performance, (b) the development of communicative competences and critical thinking, (c) scientific literacy, (d) the enculturation into the practices of scientific culture, and (e) the development of reasoning.

Research on Argumentation in Science Education

Research on argumentation in science education is a relatively recent phenomenon, beginning in the 1990s. Early studies concentrated on exploration of whether or not argumentation took place in science classrooms, often with a negative outcome in terms of children's inability to formulate sound arguments. A large number of studies focused on students' argumentation (Kelly and Takao 2002). In time, the focus shifted to the study of quality of argumentation and methodological approaches to the study of argumentation in science classroom. More recently work has been dedicated to the design of learning environments and professional development programs to support the implementation of argumentation in everyday classrooms. The emphasis in argumentation studies has varied in the work of researchers from different parts of the world. A distinctive feature of argumentation studies in Europe and in general of the attention given to argumentation throughout Europe in the last decade is its connection to the development of competences. In particular, argumentation is framed in the development of scientific competence in light of the PISA framework. In other parts of the world, for instance, in the United States, argumentation is framed in scientific practices. A great deal of research has been done in relation to argumentation in the context of socio-scientific issues (SSI). In relation to these issues, science is involved in a social debate, typically concerning personal or political decision-making related to health or environmental controversies. The notion of SSI is grounded on previous approaches as science, technology, and society or science-based social issues. While all socio-scientific issues are scientific, it needs also to be acknowledged that the controversies, either in the classroom or in society, have sometimes a stronger ethical component, while in other cases students need to appeal primarily to scientific explanations.

There have been numerous research and development initiatives across the world to integrate information and communication technologies (ICT) in argumentation studies. A key rationale for the choice of argument and argumentation as a genre in ICT has been based on the notion that learning activities should confront cognition and its foundations. In this sense, substantial amount of research has been dedicated to how best to scaffold argumentative processes ranging from generating to justification of claims. Research in the context of teaching and learning with tools such as scientific visualization tools, databases, data collection and analysis tools, computer-based simulations, and modeling tools has been widespread. Another trend in the use of ICT in argumentation research has been the contextualization of argumentation in scientific inquiry processes. ICT tools can provide a graphical platform in which participants may collaboratively construct an argument (on one computer or on different computers in asynchronous mode) or participate in synchronous discussions. The argumentative map produced during the construction or during the discussion is an artifact that participants can exploit in further activities, as opposed to face-to-face discussions from which students cannot "physically" extract previous outcomes.

A significant line of work in argumentation relies on models of professional development based on Lee Shulman' notion of teachers' "pedagogical content knowledge" as outlined by Zohar (in Erduran and Jiménez-Aleixandre 2008). Other approaches to teacher education have extended the work of educational psychologists such as Deanna Kuhn in application to science education. In the context of argumentation, advocates for effective professional development have argued that the teaching of argumentation requires a model of pedagogy that is based on knowledge construction as opposed to knowledge transmission. Teachers' enculturation into new models of pedagogy to support argumentation requires systematic and long-term professional development.

Toulmin's Model for Analyzing Arguments

Toulmin's Argument Pattern (TAP) is a model or scheme for analyzing arguments that was developed by Stephen Toulmin (1958) in his book *The Uses of Argument* (updated in a second edition in 2003). Toulmin's model is intended for the purposes of describing argumentation in practice and of studying argumentation as it is practiced in the natural languages and therefore away from the schemes of formal logic. This practical nature makes it a useful tool in order to analyze discourse in situations where new knowledge is being generated, as science laboratories or classrooms. Formal logic frameworks, while being adequate for analyzing established knowledge, may be less fit for those other fluid, ill-defined contexts. According to Toulmin, TAP represents a "practical" or "substantial" argument instead of a theoretical argument in the form of premises to conclusions.

The focus of Toulmin's model is on the function of arguments in order to justify claims, placing the validity of an argument in the coherence of its justification. In this approach a justification of a statement or set of statements is characterized as an argument to support a stated claim. He proposes to move away from the logic-mathematical model of arguments and to draw on the jurisprudential model, using it as an analogy. His goal was to elaborate a tool of analysis more sophisticated than the model consisting of minor premise, major premise, and conclusion. Toulmin suggests that the examination of the form of arguments from different fields (e.g., law, science, and politics) yields a common pattern consisting of six elements or components, claim, data, warrants, backings, qualifiers, and rebuttals, which are discussed below. This scheme is known as Toulmin's Argument Pattern or TAP.

TAP embodies some points about arguments and reasoning, as, for instance, (a) that arguments involve not only supporting points of view but also attacking them, (b) that conclusions drawn from reasoning may be qualified, or (c) that standards of reasoning can be field dependent. As Hitchcock and Verheij point out, in the introduction to a special issue of the journal *Argumentation* in 2005 devoted to the influence of Toulmin's layout of arguments, each of these points is illustrated by Toulmin's layout: for instance, rebuttals illustrate point (a), qualifier point (b), and warrant and backing point (c).

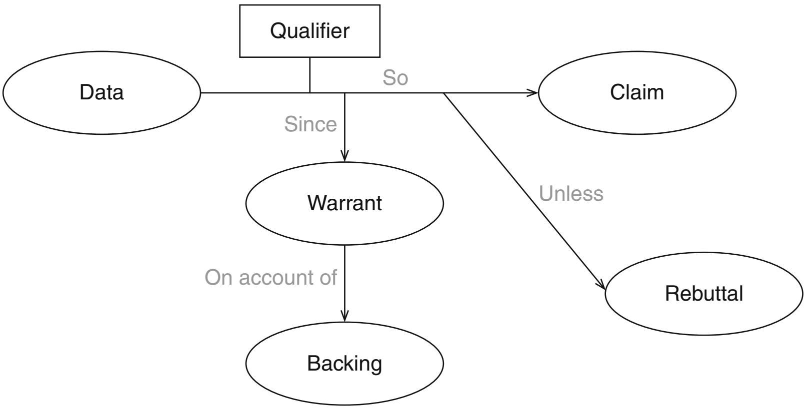
Components of Toulmin's Argument Pattern

In Toulmin's scheme, an argument, or in other words the result of coordinating an explanation with the evidence supporting it, has three essential components, in his own terms the first skeleton of a pattern: claim (C), data (D), and warrant (W). There are three components that account for other features of arguments: backing (B), modal qualifiers (Q), and rebuttals (R). Besides Toulmin's original characterization, some modifications of the components in science education literature are presented:

Claim: the statement, knowledge claim, or conclusion that has to be supported or disproved (in science, explanations seeking to interpret natural phenomena constitute a relevant sort of claim).

Data: observations, facts, or experiments that are appealed to as a foundation for the claim or, in more general terms, that are used in order to evaluate a claim. In science education the term *evidence* has been used in some argumentation contexts: it should be noted that is not fully interchangeable with *datum*. In other analyses data and warrants are collapsed under the term *evidence*.

Warrant: a statement that relates the claim to the data, in order to show that, taking these data as



Argumentation, Fig. 1 Toulmin's Argument Pattern (Toulmin 1958)

a starting point, the step to the claim or conclusion is a legitimate one. In science education the terms *justification* and *reasoning* have also been used instead of warrant.

Backing: generalizations making explicit the body of knowledge or experience relied on to establish the authority or trustworthiness of the warrants. In science education they may be, for instance, appeals to theories, and the term *background knowledge* has sometimes been used.

Modal qualifiers: indicate the strength conferred by the warrant and express the grade of certainty or uncertainty of an argument, for instance, "probably," "for sure," and "it depends."

Conditions for rebuttal: for Toulmin, they acknowledge the restrictions or exceptions to a claim. However, in analyses of argumentative contexts where a confrontation between two opposite explanations exists, a *rebuttal* means a criticism of the evidence of the opponent, as discussed in detail in Erduran's chapter in Erduran and Jiménez-Aleixandre (2008).

Toulmin also proposed a graphical representation for the relationships among these components that is reproduced in Fig. 1.

For Toulmin, some components of arguments are the same, while others differ across fields of inquiry. He termed the elements that are similar across fields as being field-invariant features of arguments, whereas those that differed were called field-dependent features. Data, claims, warrants, backings, rebuttals, and qualifiers are field invariant, while "what counts" as data, warrant, or backing are field dependent. Thus, appeals to justify claims used to craft historical explanations would not necessarily be the same kind of appeals used to support claims for causal or statistical-probabilistic explanations. The flexibility of Toulmin's model to function in both field-dependent and field-invariant contexts provides an advantage for understanding and evaluating the students' arguments in science classrooms.

Toulmin's Argument Pattern in Science Education

Toulmin's Argument Pattern (TAP) has been applied in science education in numerous ways. It has influenced the conceptualization of argumentation in science education theory, practice, and policy. Though not acknowledged explicitly, there are examples of curricular policy documents from around the world that have incorporated some of the notions and terminology embedded in the TAP framework, for instance, the Program for International Student Assessment (PISA), which emphasizes the role of evidence in the reaching of conclusions. Jiménez-Aleixandre and Erduran (in Erduran and Jiménez-Aleixandre 2008) discuss examples of steering documents and standards from different countries that incorporate ideas from Toulmin's model.

TAP has been used extensively as an analytical tool in the study of argumentation in the science classroom. As summarized by Erduran (in Erduran and Jiménez-Aleixandre 2008), apart from its methodological use, TAP has been used as a framework for understanding the nature of scientific reasoning, as a theoretical tool and representation, and as an indicator of problem-solving in expert-novice studies. In situating argumentation as a particular type of communicative interaction, Rigotti and Greco Morasso (in Muller-Mirza and Perret-Clermont 2009) propose a model that draws on the discursive nature of Toulmin's framework and may be useful for arguments in socio-scientific contexts.

Despite its various adaptations and uses, Toulmin's work has received much criticism within the science education community. A primary criticism has centered on the issue of difficulty in capturing dialogic argumentation. It has been argued that Toulmin's scheme is a model of rationale discourse adequate primarily for a monologue, although the inclusion of the modal qualifier can be conceived as the introduction of an element of dialogue. Richard Duschl (in Erduran and Jiménez-Aleixandre 2008) advocates that the focus of argumentation analysis should be on epistemic criteria and that TAP is not effective for the purposes of the clarification of "what counts" as claim, data, warrant, and backing or, in other words, the field-dependent dimensions of arguments. Duschl proposes Douglas Walton's reasoning schemes as an alternative to analyze dialectical exchanges in science classrooms. Further methodological difficulties have been described by other researchers, as, for instance, that organizing student discourse into Toulmin's argument components required careful attention to the contextualized use of language. Kelly and Takao (2002) discuss the ambiguity of Toulmin's categorical system, pointing out that in the context of actual arguments, claims may serve as data in more complex chains of reasoning, as is the case in written arguments. A second criticism raised by these authors is that Toulmin's approach does not consider the relative epistemic status of knowledge claims. In order to address these shortcomings, Kelly and Takao developed an analytic framework focused on the epistemic level of propositions within an argument and how they are connected within and across levels.

Apart from research-based applications of TAP in science education, there are examples of work where TAP has been used to inform the production of resources for teaching and learning as well as professional development of science teachers. For example, TAP has been used to structure the students' writing of arguments and the design of training programs for teachers. The adaptation of TAP as a structure and a process of argumentation has also yielded understanding of the hierarchy of pedagogical strategies that underlie effective teaching of argumentation (Zohar in Erduran and Jiménez-Aleixandre 2008).

Future Perspectives

Despite wealth of research in classroom-based research on argumentation since the mid-1990s, reviews suggest that the territory remains ripe for numerous lines of work in the future. An aspect of argumentation research that has not been addressed sufficiently in the literature is the relationship between disciplinary content or conceptual knowledge and argument structures and processes. There is also little work dedicated to the exploration of students' and teachers' perceptions of argumentation. Likewise, developmental trajectories of teachers in learning argumentation in a longitudinal fashion are virtually nonexistent. Future studies could build on investigations on the cultural or contextual factors that impact teachers' and learners' argumentation in science classrooms. The study of emotions, gender, and power relations in relation to argumentation is virtually inexistent in science education research. While acknowledging the potential of argumentation to engage students in scientific practices, McDonald and Kelly (in Khine 2012) point out the limitations of an increasingly specific focus on argumentation in student discourse, for instance, narrow focus on one type of discourse and analytic limitations in terms of understanding the quality of students' classroom science discourse. They suggest scientific sensemaking as a broader perspective on science discourse practices that would be more productive to support both science teaching and learning and science education research. This perspective may be one future direction for the integration of argumentation studies in broader frames. A fruitful new territory for argumentation research could draw from "science studies" – the interdisciplinary studies on science with implications for science education.

Cross-References

- ▶ Argumentation Environments
- ▶ Discourse in Science Learning
- ▶ Scientific Language

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Argumentation Environments

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Definition

Argumentation environments are computer-based systems that engage and support learners in constructive and collaborative activities around argumentation, such as creating, editing, communicating, interpreting, and/or critiquing arguments. Scientific argumentation, as a process of building upon or refuting claims based on empirical evidence to arrive at agreed-upon scientific conclusions, challenges learners in that it requires both conceptual understanding of relevant content knowledge and mastery over various problem-solving and social skills. As such, argumentation environments typically consist of technology-based tools integrated into extended face-to-face or computer-supported activities for K-16 students and designed to address the dual pedagogical goals of helping students learn the practices of scientific argumentation (learning to argue), as well as the content knowledge necessary for engaging in those practices (arguing to learn) (Scheuer et al. 2010).

Features of Argumentation Environments

Two kinds of argumentation environments may be distinguished. Discussion-oriented argumentation environments emphasize the use of arguments in collaborative dialogue among peers, whereas argument modeling environments support the creation of arguments, often by piecing together primitives and testing these against an underlying model. Whether a system is discussion- or modeling-oriented has large impacts on the possible kinds of learner interactions, automated analyses, and feedback that can be generated. However, any one system may feature characteristics of both categories. Generally, although to varying extents, the tools within argumentation environments focus on scaffolding idea generation; information seeking; text planning, structuring, and linearizing; argument expansion, elaboration, and evaluation; and collaboration and debate. The manners by which these scaffolds are manifested reflect designers' pedagogical goals and theoretical perspectives on argumentation (Clark et al. 2007). Nevertheless, argumentation environments typically include several features in common (Hilton 2010): (1) contextualizing representations, (2) access to relevant content information, (3) support for communication and collaboration, (4) argument representations, (5) socio-cognitive structures, and (6) metacognitive supports.

(1) *Contextualizing representations* embed argumentation in an overarching activity, helping learners realize the relevance of argumentation and motivating them to apply their knowledge and skills in meaningful ways. Students are either presented with or allowed to explore representations such as narrative, images, video, and other interactive media. These serve to establish a problem scenario and prompt students to develop solutions, in which they must take on particular perspectives, seek information, and justify and communicate their claims.

(2) *Access to relevant content information* helps reduce learners' cognitive load when engaged in constructing and communicating arguments. Through explorable content-rich representations, students may access student-generated or curriculum author-generated databases of information from which they may gather information to help establish a perspective on a given topic and to use as evidence in support or refute of claims in their arguments. These databases may be contained such that students explore it without leaving the environment, or else they may be provided access to external resources, such as the World Wide Web. Often, tools associated with these information databases support information processing tasks, such as gathering, documenting, and sorting information, as well as managing sources of that information. These tools allow students to create and maintain intermediate representations toward preparing final arguments. For example, some tools may allow open-ended note-taking, list creation, or direct annotation on an information source. Such tools may furthermore support cognitive actions such as sorting, grouping, and tagging individual information entries, that together help students prepare to formally present their ideas.

(3) *Support for communication and collaboration* generally consists of shared spaces with tools to promote social interactions and to encourage learners building and negotiating joint understandings. These supports often afford the co-construction of artifacts, including knowledge repositories, intermediate representations, as well as text and diagrams of final agreed-upon arguments. They may also offer platforms on which learners can review, critique, and debate each other's points of view.

Environments differ in the degree to which the computer mediates learners' interactions. For example, certain systems have embedded support for such communication and collaboration and thus allow interactions among spatially or temporally separated individuals via an entirely virtual space. In these cases, tools may permit synchronous and/or asynchronous communication among students via real-time chat applications or archived discussion forums. Other environments support only single-user interaction, but may instead promote face-to-face interactions within groups of students sharing the same computer station, or among individuals via a group projection system. Still other systems may support individual learners through student-to-computer interaction.

(4) *Argument representations* are the ways by which arguments are presented to learners. By offering visual ways to externalize ideas as learners formulate or review the structure of their arguments, they allow learners to recognize, through visual inspection, the relations between elements as well as any missing components of their arguments. Argument representations vary in appearance, often taking the form of text containers, linear or threaded discussions, matrices, or node-link graphs. They may also vary in the manners by which learners are able to interact them. For example, some representations may be individually or collaboratively constructed and may scaffold the construction of particular argumentative structures by limiting, requiring, or allowing learners to create any number and particular kinds of elements and relations between them. Other representations may be system generated and provide learners with artifacts for inspection, reflection, and critique. Certain systems

display argument representations as part of a linear series of activities, whereas others support the simultaneous use of multiple representations. Argument representations tend to reflect the particular conceptual primitives that make up an argument (e.g., hypothesis, data, evidence) and which differ depending on designers' underlying theoretical perspectives.

(5) *Sociocultural design* involves specifying and guiding sequences of activities to maximize the success of interactions among learners, as well as the quality of learners' resulting arguments. For example, some environments orchestrate social interactions by distributing roles in which learners must take on particular perspectives and tasks. Other systems group learners based on personal characteristics (e.g., gender, prior knowledge) or on their similar or opposing views determined from learners' responses to previous items. Still other systems moderate learner discussions in various ways, such as by seeding discussions with predetermined topics.

(6) *Metacognitive supports* encourage learners to monitor and reflect upon their understanding and on the quality of their own and of others' contributions. Supports may include visual or numeric displays that give learners information on group dynamics. These may include participation metrics in terms of interactions had with others and of contributions made or requiring attention by themselves and others during joint tasks. They may also include displays of socio-cognitive information in terms of levels of certainty and agreement among group members. Metacognitive supports may also involve various kinds of feedback, either generated by a human moderator or by the system itself. For example, learners may receive adaptive feedback on the quality of their contributions based on automated analyses of their submitted work, or generic text prompts to reflect upon the state of their understanding and to make decisions about the information they may require to further refine their ideas.

Assessment and Feedback

The technological capacities of computer-based argumentation environments offer various ways to assess and understand how people learn through argumentation and how such systems can support them (Scheuer et al. 2012). These techniques vary in sophistication depending on the nature of the objects of assessment, whether these consist of learners' natural language contributions or entries in tightly constrained input fields. Generally, analyses of argumentation focus on identifying the content and patterns of learners' discussions in order to characterize how learners communicate with one another. From archived interactions within a system, for example, researchers can count and categorize the kinds of exchanges that occur between learners in terms of their argumentative functions (e.g., claims, warrants, evidence). Machine learning and artificial intelligence techniques can also be used to automatically identify patterns in the structure of learner-generated arguments and to evaluate their quality in terms of their positive attributes (e.g., evidence-backed claims, logical chain of reasoning) or negative ones (e.g., irrelevant contributions, lack of responsiveness). By then relating these measures to assessments of learners' content understanding and other interactions in the environment, researchers may gain a sense of how conceptual learning and argumentation skills develop over time as a result of learners' interactions in the environment. Results from these automated analyses may then be used to generate various forms of feedback (formative, summative) at different times (immediate, on-demand), from different sources (human moderator or system generated), and in various modes (text messages, colored highlighting). Automated feedback may either be sent to teachers to inform them on how to guide subsequent activities, or it may be delivered directly to the learner.

Implications for Learning

There are several educational benefits of learning through argumentation that features of argumentation environments, such as scaffolded role play, co-constructed artifacts, and dynamic argument visualizations, aim to support (Andriessen 2006). For instance, learners not only become familiar with various argumentative structures, but by engaging in key processes of argumentation such as elaborating, reasoning, and reflecting upon ideas, students achieve deeper understandings of those ideas. Furthermore, by participating in argumentation, students develop their sense of social awareness and their skills in collaborating with others. At the same time, practice in argumentation helps students become better at arguing, and thus, more competent members of knowledge-based professional communities.

Online argumentation environments can furthermore support specific twenty-first century skills. They develop learners' adaptability to changing information and contexts by scaffolding investigations into unfamiliar topics and distributing roles that give learners practice taking on perspectives different than their own. They also develop complex communication skills by providing learners with tools that orchestrate productive interactions with their peers and that scaffold them articulating their ideas. Argumentation environments furthermore support non-routine problem-solving by helping learners seek patterns and explore alternative perspectives as they evaluate and integrate large amounts of seemingly disparate information. They support self-management and self-development by providing students with tools for monitoring and reflecting upon their own and their peers' contributions. Finally, these environments develop learners' systems thinking skills in that arguments are themselves systems of functional components; thus, scaffolding tools in argumentation environments help students consider how various pieces of information fit together to form a coherent whole.

Research shows impacts of argumentation environments on students learning to argue. Indeed, depending on how they are designed and used, the scaffolding features in argumentation environments have the potential to support students' developing argumentation skills that equal or exceed what is observed in oral argumentation. At the same time, another research suggests that students better manage their argumentation activities face-to-face than mediated by a computer. Designers thus strive to create learner-centered environments that maintain the benefits of face-to-face interaction while capitalizing on the advantages of technology for providing adaptive instruction and for relieving the burden on teachers to provide individualized support to large classrooms of students during open-ended science inquiry activities.

Software Architecture and Technology

A number of free and proprietary software exist that have been explicitly designed to support argumentation in educational science inquiry settings (e.g., as opposed to argumentation in the legal, political, or social sciences domains). Currently, most of these argumentation environments are built upon unique software architectures that are independent of prior technology developments. They use two primary formats to save and exchange data between systems: state based and action based, each of which offers different affordances for automated analysis and feedback. Other domain-general software tools, such as wikis, blogs, forums, and diagramming tools, have been appropriated to support argumentation in educational science inquiry settings.

Examples of Argumentation Environments Developed for or Used in Science Education

- Belvedere (http://belvedere.sourceforge.net/)
- Collaboratory Notebook (http://www.covis.northwestern.edu/software/notebook/)
- CONNECT: Confrontation, Negotiation, and Construction of Text
- Convince Me (http://hamschank.com/convinceme/)
- CSILE: Computer Supported Intentional Learning Environments (http://www.knowledgeforum.com)

- Digalo (http://www.argunaut.org/glossary/Digalo)
- Digital IdeaKeeper (http://www.umich.edu/~hiceweb/downloads/QuintanaAERA04.pdf)
- DREW: Dialogical Reasoning Educational Web tool (http://drew.emse.fr/)
- ExplanationConstructor (http://pages.gseis.ucla.edu/faculty/sandoval/research/projects/excon/)
- Idea Manager (http://wise.berkeley.edu/webapp/pages/features.html)
- Rashi (http://ccbit.cs.umass.edu/RashiHome/)
- Sensemaker (http://tels.sourceforge.net/sensemaker/)
- TC3: Text Composer, Computer supported and Collaborative (http://www.academia.edu/375095/Coordination_Processes_In_Computer_Supported_Collaborative_Writing)
- VCRI: Virtual Collaborative Research Institute (http://edugate.fss.uu.nl/~crocicl/vcri_eng.html)

Cross-References

▶ Argumentation
▶ Communicating Science, Classroom Assessment of the Ability to
▶ Computers as Learning Partners: Knowledge Integration
▶ Discourse in Science Learning

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Asian Ancestry

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In traditional Asian cultures, especially the Confucius tradition in East Asian countries, teachers were regarded as exemplary persons with knowledge, life experiences, wisdom, and compassion toward the world. Teachers were highly respected by the members of community; thus, their teaching and contributions to the community were influential and well accepted. Teacher-student relationship was built based on respect, trust, and care for each other. The traditional ways of knowing are based on the Confucian understanding of teaching and bringing up the younger generation to become good human beings with knowledge and wisdom (Hall and Ames 1987). Education was valued and teachers' status was high. Even though most educational traditions and practices have changed in response to modern societal changes, education is still highly valued and emphasized in Asian cultures.

Asian countries were rapidly industrialized and globalized in the nineteenth and twentieth centuries, adapting and transforming modernized education models from Western societies such as school subjects, school systems, curriculum, etc., into their local situations. In many Asian countries, schools use the same national curriculum which is authorized by the government. In junior and senior high schools, science is taught by science teachers who specialized in science and science education (specifically biology, chemistry, physics, and earth science).

Elementary science is taught mostly by teachers who specialized in elementary education, not specifically in science.

One of the current fundamental issues faced by teachers and students in Asian countries is the assessment system. In many countries, there are exam systems to evaluate students' knowledge and skills for university entrance. Such assessments have resulted in content-based curriculum and teaching practice in public schools (Kim et al. 2013) and also caused the emergence of problematic private education involving private tutoring and cramming for exams.

Despite the high level of student achievement in international assessments in science (e.g., TIMMS, PISA), exam-focused education in Asian countries has caused concern about students' creativity, inquiry skills, and attitudes toward science (Bybee and McCrae 2011). Recognizing this concern, many countries have started to recognize the importance of critical thinking, creativity, and problem-solving skills for the twenty-first-century learners and have attempted to innovate science curriculum and teaching practice with inquiry focus (Kim et al. 2013).

Cross-References

- ▶ Black or African Ancestry
- ▶ Cultural Influences on Science Education
- ▶ Cultural Values and Science Education
- ▶ Latino Ancestry
- ▶ Pacific Island Ancestry

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Assessed Curriculum

▶ Curriculum

Assessing Science Communication: An Overview of the Literature

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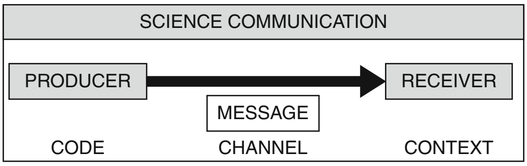
Introduction

The literature on assessment of science communication in classroom settings is vast and focused on a broad range of communicative behaviors, including talking, writing, reading, and listening. One useful way of understanding this literature is in terms of a message transmission model (see Fig. 1) wherein teachers and students take turns playing the roles of producers and receivers of a science message. A message (scientific information) is produced in a linguistic code (e.g., the English language) and transmitted via a particular channel (oral or visual) through the performance of communicative acts (e.g., utterances or texts) in a given context (e.g., whole-class discussion, lab write-up, written test). From this perspective, science communication entails production as well as reception of a scientific message. Much of the existing research has focused on the assessment (formal and informal) of one or more of these different dimensions of science communication.



Assessing Science Communication: An Overview of the Literature, Fig. 1 Message transmission model of science communication

Communicative Production of Science

The primary focus of this literature is the assessment of student-written production of science. Various studies have examined the use of writing templates to scaffold student-written communication in the context of science inquiry activities. The Science Writing Heuristic (SWH) is one such tool that has been used widely. Theoretically, the SWH represents a bridge between more personal, expressive forms of writing and the recognized form of the genre, the scientific laboratory report, which represents canonical patterns of presenting results, most especially the link between claims and evidence.

The SWH guides student-written communication through the provision of a series of prompts (What are my questions? What did I do? What did I see? What can I claim? How do I know? How have my ideas changed?). Keys et al. (1999) describe how the use of SWH in an eighth grade earth science class improves several aspects of student-written communication in science lab reports, including evidence-based reasoning, nature of science, and metacognition.

Considerably less attention has been given to the assessment of teacher production of science messages (both oral and written). One exception is a recent study by Glass and Oliveira (2014) who assess the communicative practices of five elementary teachers faced with the task of orally delivering a science text of relatively high linguistic complexity. Assessment of teacher oral production was conducted quantitatively through the combined use of two computer programs to measure relative linguistic complexity of both speech and text: the Simple Concordance Program SCP4.9 and the vocabulary profiler Classic-VP English v.3. This computer-based assessment revealed that oral discussions had an increased percentage of less sophisticated words (everyday parlance) and reduced use of more sophisticated vocabulary (academic terms) than found in the science books. In other words, teachers resorted to accommodation (i.e., provision of simplified linguistic input) in order to promote student comprehension (i.e., reception) of the textual contents of children's science books.

Lastly, some research has also been conducted on science curriculum developers' communicative production of written messages, particularly in science textbooks. Catley et al. (2010) point out that noncladogenic diagrams (ambiguous evolutionary depictions that place organisms in a linear progression rather than nested sets) in biology textbooks and popular science articles miscommunicate macroevolution as a process of biological change that is both anagenic (an entire species directly evolving into another rather than splitting or branching into two) and teleological (purpose or need driven). This research highlights the potential for visual miscommunication of science in curricular materials at the secondary and college levels.

Communicative Reception of Science

Research on the receptive end of science classroom communication has been primarily focused on the assessment of student reading, often underscoring students' difficulties in making sense of expository science texts written in the scientific genre. Norris and Phillips (1994) report that high school students tend to disregard hedges (tentative expressions such as probably, possibly, approximately, and occasionally) when reading popular science texts from the media and are generally unable to interpret those hedges as signals of tentativeness and inconclusiveness. In addition to ascribing higher certainty to the text than originally intended by the author, many students also misunderstand the epistemic status of written statements in popular science reports, often confusing justifications with evidence and conclusions.

Several studies have also examined students' reception of graphical or visual messages from curricular materials (e.g., pictorial representations in science books). This research shows that poorly designed images can lead to misunderstanding and confusion in picture-based science communication, regardless of topic or grade level. Colin et al. (2002) describe secondary students' difficulties in interpreting textbook images of optical phenomena (diffuse reflection, Young's principle of interference, converging lenses, Romer's discovery of the finite speed of light, and colors), including a tendency to ascribe a realistic status to light rays (represented by arrows), a story-like view of optical phenomena due to the classical left-to-right orientation of textbook illustrations, and mistaking colored lights for paints.

Conclusion

In sum, the existing literature highlights the multifaceted and diverse nature of science classroom communication. Communicative assessment can focus specifically on the production or reception of varied types of messages (speech, texts, visual images, etc.) by varied parties (science instructors, learners, curriculum writers, etc.) and take place in many types of contexts (classroom discussions, silent text reading, visual inspection of curricular images, etc.). Careful and reflective consideration should be given to these different aspects or dimensions in effort aimed at assessing the quality of communication in science classroom settings.

Cross-References

- ► Communicating Science, Classroom Assessment of the Ability to
- ► Communicating Science, Large-Scale Assessment of the Ability to

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Assessing Students at the Margins

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Assessing students at the margins can refer to either or both nonmainstream *students* or nonmainstream *settings*. The former might be females, students of color, or students from a language background other than English. For science education, nonmainstream settings include contexts such as museums and community-based programs.

Regardless of the particular student population or context, fairness in the assessment process is key. The *Standards for Educational and Psychological Testing* (AERA et al. 1999) describe fairness as encompassing lack of bias, equitable treatment, equality in outcomes, and opportunity to learn. The latter notion is further conceptualized by Pullin and Haertel (2008) to include the content taught and educational resources as well as classroom processes. Attention to these issues is important for all students; it is even more so for nonmainstream students who are often misrepresented or underserved by the assessment process.

From an assessment design perspective (Shaw 2005), the use of bias review panels and the approach known as universal test design (Thompson et al. 2002) aim to remove potential barriers and biases, while an assessment is being developed. For example, consider students whose native or primary language is different from that of the test, known as English learners (ELs) in the USA. Eliminating complex language that is irrelevant to the content being assessed can make assessment items more accessible to such students, thus improving the accuracy of the information provided by the assessment. With respect to assessment delivery, accommodations such as longer time and use of bilingual glossaries have been shown to increase fairness for ELs without advantaging them over native English-speaking peers (Abedi et al. 2004).

In many cases, the above strategies are coming to be seen as mainstream approaches for assessing students at the margins. They are readily applicable to school-based assessments, be they teacher-developed or large-scale external. Yet science learning is not confined to the four walls of a classroom. Assessment in nonmainstream settings offers interesting challenges and opportunities. In such settings comparability may be less of a concern such that standardization has less importance. Grasping what students have learned and are able to do is still worth knowing.

Fusco and Barton's (2001) work with a community-based science program offers insights to assessment in settings at the margins. Their efforts focused on performance assessment, which they saw as "an excellent resource to help create a participatory and inclusive practice of science that draws more closely and critically from the culture and practices of young people" (Fusco and Barton 2001, p. 352). This vision of fairness redefines marginalization through student advocacy, agency, and empowerment. Such "learner relevant assessment" strives to improve learning through critically incorporating student knowledge and background into all phases of the process.

Learner relevant assessment calls for an expanded definition of opportunity to learn and its consideration of what is taught as well as how. It draws on the notion of "culturally relevant pedagogy" and its propositions of students' academic success, cultural competence, and critical consciousness (Ladson-Billings 1995). Learner relevant assessment connects also to the concept of "cultural validity" (Solana-Flores and Nelson-Barber 2001), the effectiveness with which assessment addresses the socio-cultural influences that shape student thinking and the ways in which students make sense of items and respond to them (p. 555).

Learner relevant assessment envisions a process of assessment influenced by nonmainstream students' "daily lives, the assets they bring to [assessment] practices," along with "the possibility of a co-opted [assessment process] that would be respectful of who they are and are becoming" (Rahm 2010, p. 4). This is what assessing students at the margins is truly about.

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Assessment Framework

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Keywords

Assessment framework; NAEP; PISA; TIMSS

Assessment frameworks are guides for the design of the assessment. These portray the structure of the assessed curricula providing a context for discussing the purpose of the assessment and what it is trying to measure.

Trends in International Mathematics and Science Study (TIMSS) framework include mathematics, science, and contextual frameworks. There are defined mathematics or science content domains covered by the assessment at fourth and eighth grades. Each topic area belonging to a content domain is presented as a list of objectives written in terms of student understandings or abilities that items are designed to elicit. There are also defined three cognitive domains – knowing, applying, and reasoning, at both fourth and eighth grades, mathematics and science. The understandings and abilities required to engage in scientific inquiry are included within the two dimensions of the assessment framework – the content and cognitive dimensions. Contextual framework identifies the major characteristics of the educational and social contexts that will be research for improving student learning (Mullis et al. 2009).

Programme for International Student Assessment (PISA) framework presents reading, mathematics, science, and questionnaires frameworks. The concepts of *reading literacy*, *mathematical literacy*, and *scientific literacy* are described in terms of the skills students need to acquire, the processes that need to be performed, and the contexts in which knowledge and skills are applied. Accessing and retrieving information, forming a broad general understanding of the text, interpreting it, reflecting on its contents, and reflecting on its form and features are considered key aspects in demonstrating the students' proficiency in reading. Mathematical literacy is assessed in relation to mathematics contents defined mainly in terms of four overarching ideas (quantity, space and shape, change and relationships, and uncertainty) and to processes (the use of mathematical language, modeling, and problem-solving skills) in five situations (personal, educational, occupational, public, and scientific). The assessment of scientific literacy is designed in relation to scientific knowledge or concepts related to science in life and health, science in Earth and environment, and science in technology. It also targets the following processes: acquire, interpret, and act upon evidence. PISA questionnaire framework presents the information to be collected at four different levels: the educational system as a whole, the school level, the instructional setting, and the student level. It presents also some dimensions for the analyzing the policy relevance of the data (OECD 2010).

The National Assessment of Educational Progress (NAEP) framework encapsulates a range of subject-specific content and thinking skills appropriate for the testing of three grade levels – 4, 8, and 12 (http://nces.ed.gov). In addition, NAEP framework contains details about the design of the context questionnaires addressed to school, teacher, and student that helps to understand student achievement in context. The framework serves for revising curricula and also could serve as model for measuring the skills in innovative ways.

Cross-References

- ▶ Assessment: An Overview
- ▶ Inquiry, Assessment of the Ability To
- ▶ National Assessment of Educational Progress (NAEP)
- ▶ Programme for International Student Assessment (PISA)
- ▶ Scientific Literacy
- ▶ Third International Mathematics and Science Study (TIMSS)

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Assessment of Doing Science

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Keywords

Curriculum; ICTs; Laboratory Work; Representation; Summative

This contribution examines assessment practices associated with the "doing of science." All assessments are predicated on assumptions about *what* knowledge is of value and *how* this knowledge might be developed and made visible. Hence this contribution begins by reviewing developments in the goals for science education and then considers how assessment practices associated with the goals of "doing science" have played out in different ways for different purposes at the different levels of the education system (international, national, and classroom). Issues associated with the equity and inclusion, the situated and social nature of learning, and the use of information and communication technologies are also addressed.

What Is Involved in Doing Science? A Focus on Expansive Curriculum Goals

Hands-on and practical tasks are widely recognized as a distinctive feature of school science, but the nature of these activities along with understandings of what is involved in doing science has changed over time. The interrelated nature of curriculum, pedagogy, and assessment has meant that shifts in curriculum goals have required innovation in both pedagogy and assessment. It is no longer sufficient that teachers monitor student conduct of a teacher-prescribed confirmatory experiment or even the development of student investigative skills per se. Curriculum, pedagogy, and assessment need to combine to develop students as citizens who are willing, able, and sensitive to occasions when they could take science-informed actions in their homes and communities. Students need to appreciate how scientists generate, legitimate, and communicate science and to meet the demands of the "knowledge society" they need to develop the capacity to be lifelong learners of science. Given that assessment is a key message system for according value within schools, any assessment of students "doing" science needs to encompass and attend to the full breadth of these learning outcomes.

Research has highlighted the value of pedagogies that explicitly focus on the development of student argumentation, modeling and scientific reasoning capabilities, and the affordances of units that are grounded in socio-scientific or local issues and that offer students with opportunities to participate in science inquiry. The implementation of these pedagogical approaches has required analysis of the nature of the learning outcomes aimed for, what performances would indicate proficiency in a given outcome, and what kinds of tasks would develop and require the desired learning outcomes. The new pedagogies have demanded and afforded new opportunities for student assessment to make visible what students know and can do.

Who Is Assessing and Why?

A consensus is emerging that better assessments need to be developed to capture and communicate the breadth of student learning across all levels of the educational system. International organizations such as the OECD and UNESCO, national and state governments, and schools, teachers, students, parents, school communities, and employers are all important stakeholders in and audiences for the assessment of student achievements in the doing of science, albeit for different reasons and consequences. While the assessment needs at each of these levels are not the same, it is desirable that assessments at the different levels come together to support a common set of learning goals, rather than working at cross-purposes. A balance needs to be achieved between formative assessment, where the intention is to support and enhance teaching and learning, and summative assessment that sums up and reports on student achievement at a particular point of time for accountability and certification purposes.

Internationally the PISA has been influential in directing attention to scientific literacy as a key outcome for science education (OECD 2013). It has contributed to developments in the assessment of student science capabilities through the use of context-based assessment items and the assessment of student knowledge and attitudes. In 2006 and 2009, PISA pilot-tested the computer-based assessment of science (CBAS), designed to measure science knowledge and inquiry processes. Combined, these developments have been important through a wash-back onto national priorities and practices and, subsequently, onto classroom teaching and student learning.

At the national level, countries around the world have moved to include learning outcomes to do with inquiry and scientific practices in their assessment for system accountability and student qualification programs. Policy and practice reviews to date suggest that the nature and level of specification of outcomes from practical and inquiry learning are variable within and across the years of schooling and across country settings. There is no clear evidence for what level might be optimal in terms of supporting valid, reliable, and productive teacher and student assessment practices. Current concerns at the national level in many countries revolve around the potential for assessments designed for system accountability to restrict curriculum time spent on science at the primary school level and to narrow the science curriculum at all levels of schooling to material that can readily be tested through paper-and-pencil-type tasks. In the USA and UK, there is evidence that this is limiting student opportunities to experience the practical data/knowledge generating and testing aspects of science.

At the classroom level, researchers are continuing to find that teacher instruction and assessment at the beginning, throughout and at the end of practical and inquiry tasks, are often restricted to conceptual outcomes. From their actions it seems that teachers assume that student understanding of links between concepts and theories and of science-specific ways of generating, validating, and reasoning with and representing evidence will emerge from their observations of phenomena, and so they miss opportunities for formative assessment to support students to make these connections.

Student involvement in the assessment of their progress through self-assessment is important from an assessment point of view as a means for fostering student learning capacity and autonomy. It is essential within student-directed inquiry. Additionally, student involvement in the assessment process through peer assessment is important from an assessment point of view as a source of timely and focused feedback. It is congruent with students having opportunities to engage in and gain expertise in argumentation, reasoning, and modeling as part of explaining and justifying their science ideas to others. Collaboration and critique are important aspects of how scientists work and central to many current pedagogical innovations. However, a collective focus poses a challenge for assessors once the goal moves beyond supporting learning (formative assessment) to documenting for others what science an individual knows and can do (summative assessment). This matter is one that requires further exploration given the “social turn” in understandings of learning and the strength of research evidence and wide policy recognition that all assessments should, and can, support teaching and learning in some way.

Very little attention has been paid to parents and school communities as stakeholders for assessment beyond their being an audience for information on individual student achievement or school-aggregated information. Curriculum aspirations that include students being able to continue learning science and take science-related actions in their everyday lives, coupled with proposals that community linkages can support the engagement in science of disenfranchised student groups, suggest that this is an area in need of development.

The How of Assessment of "Doing Science"

The assessment of students' doing of science is challenging and has been made more complex as the goals for science education have expanded to include student participation in inquiry, modeling, argumentation, and so on. Recognition of the situated social nature of learning and its links to the transformation of identity has added further complexity. Some of the key challenges and practices include those related to the relative merits and practicality of direct and indirect assessment of student practical/inquiry competencies, of holistic or component assessment of student inquiry capabilities, of individual or student group practices, and of the use of multiple modes and means (Harlen 1999; Hodson 1992). At the same time, research is emerging that suggests information and communication technologies; the development of learning progressions for particular topics and for inquiry practices has the potential to help policy makers, curriculum developers, and teachers meet these challenges.

Debate exists about the relative merits and practicality of direct and indirect assessment of student practical/inquiry practices, skills, and orientations (Reiss et al. 2012). With direct assessment student practical and inquiry skills are assessed by teacher observation of students as they engage in an investigative task. With indirect assessments student competency in terms of a specific or generic skill is *inferred* from their reports of the work they have undertaken or via pencil and paper test questions. Several studies have found differences in student performance in practical investigations, depending on whether a direct assessment mode or a written assessment mode is used. It has suggested that written tasks elicit evidence of what students *know* about practical work/inquiry and how it should, in principle, be undertaken rather than on their competency in terms of actually being able to *do* practical work themselves. Typically, direct assessment is advocated as it captures both the process and the product of student learning.

With regard to high-stakes summative assessment, including assessment exit qualification purposes, different countries use different combinations and forms of direct and indirect assessment. Tasks used in direct assessment can be teacher or externally designed, supervised, graded and the grades moderated, to various degrees. Often the awarding body provides a bank of tasks and of exemplars of student responses at different levels of achievement to support teacher grading. In some contexts direct assessment data is collected on one occasion; in other contexts it is collected over a range of tasks, contexts, and topics. In the UK, for example, the collection of data is loosely controlled by the teacher and can be undertaken by a group, but the analysis and communication of results are done individually under test-like conditions.

Given the influence of high-stakes assessment on curriculum and pedagogy, it might be expected that the inclusion of inquiry and practical work in high-stakes assessment would promote and enhance the teaching and learning of these aspects. In contrast, studies are emerging that indicate the tendency to train students to do investigations has had the effect of conflating the teaching, learning, and assessment of investigations. Research has identified that teachers can narrow their practice of formative assessment to ensuring students comply with criteria required for the award of external qualifications credits. It also appears that to yield good marks within the full range of possible scores, teachers tend to select investigations that they are familiar with which then restricts the pool of investigations students experience and limits their involvement in investigations they develop for themselves. The issues to do with the reliability of teacher judgments and of teachers teaching to the assessment have also been identified, raising questions about the validity and reliability of student results. A counterargument is that such teaching to an assessment is only problematic when an assessment task is limited in its expectations of students; otherwise teacher scaffolding would be seen as part of enhancing the alignment of pedagogy and assessment with desired student performances.

Outside formal summative assessment, teacher classroom assessment practices tend to span a continuum of integration with teaching and learning from more formal and planned to embedded and on the fly. Ongoing informal teacher formative assessment via interaction generates information on student learning that is generated and used in the same context to provide feedback on student learning. The use of interaction coupled with curriculum-embedded assessment tasks, including the collection of student workbooks, where the information is used formatively has been found to effectively support student learning as teachers scaffold and guide student inquiry. Although contested, there is some evidence that teachers can accumulate evidence through these means that can then be revisited to make a summative judgment about student achievement that takes account how and what they have learned.

Task design is a key aspect of instruction and assessment. Sociocultural views of learning and assessment, which are currently exerting a substantial influence in science education and assessment research, recognize the situated social and cultural nature of learning and its expression or demonstration. From this perspective, student practical work and inquiry processes and products cannot be evaluated in isolation from the context of production where this context includes the task format, topic, and other resources in the assessment setting although the extent to which these contextual and content-related elements influence student performance is still a matter of debate. There is considerable research support for the use of authentic situations and real-life contexts as part of teaching and formal assessment but student familiarity/lack of familiarity with a context and its meaning in their community and culture can be a source of bias. Suggestions to address these matters include finding contexts likely to be unfamiliar to all students and the compilation of a portfolio of student work across the range of contexts students encounter in class. Other suggestions are to use different contexts for different topics and to incorporate more contexts by assessing smaller, specific aspects of an inquiry. Counter to many of these suggestions, research has demonstrated the key contribution of content knowledge in student practical work and inquiry with little evidence of the generalizability of skills assessments across science subjects. In addition, there is some evidence suggesting that the conduct of an investigation is largely a holistic task and breaking it down into separate skills might misrepresent the essence of the process, which requires the integration of a variety of skills and ideas and thus of student capabilities. These matters of context familiarity and presentation are of particular importance when test results are used to determine students' further study or career options.

Context-based performance assessments can support students to demonstrate abilities in scientific inquiry by requiring them to interact in various social groupings and use a variety of communicative modes. However, this aspect of performance assessments can be affected by student cultural norms. For example, some communities do not socialize their children to making public displays of achievement such as those valued in schools; others place an obligation on the more knowledgeable person to share their knowledge, irrespective of their ages, while still others value the production of a high-quality physical product.

Advocates of performance assessment argue that it provides students with more flexibility and options for expressing what they know and can do and recommend it as a means for accommodating student diversity and addressing issues of equity and inclusion. However, contextualized summative tasks come with reading and representation interpretation demands for student understanding of the context and what is required of them. Students, particularly, those whose first language is not English can find it difficult to make sense of a task and express what they know quickly and easily when a written response is required. Opportunities to edit or to display their knowledge in less language-embedded tasks can be of benefit to these students as can curriculum-embedded performance assessments that are subsequently aggregated to produce a summative assessment of student learning.

Modern digital and information and communication technologies present new possibilities and new challenges for teaching, learning, and assessment through the variety of means they afford for investigating phenomena; for generating, analyzing, and representing data; for working collaboratively; and for the communication of ideas to an audience. The ability to capture student inputs permits collecting evidence of processes such as problem-solving strategy use as reflected by information accessed and selected, numbers of attempts, approximation to solutions, and time allocation. Recent developments include the trialing of adaptive testing, including knowledge and skills diagnosis, the provision of immediate feedback to teachers and students accompanied by scaffolding for improvement, and the potential for accommodations for special populations.

Technology-based simulation tasks can support students to design and conduct experiments, including them being able to quickly and efficiently pose and answer a series of "what if" questions as they change different variables. Findings can be graphed or represented in a variety of ways prior to students reaching a conclusion and writing a final response. Because simulations use multiple modalities and representations, evidence is emerging that students with diverse language and experiential backgrounds may have better opportunities to demonstrate their knowledge than are possible in text-laden print tasks. Students can use video, digital photographs, and audio to document and provide commentary on their own learning journeys.

A number of research groups are exploring the viability of web- and simulation-based units that incorporate tools for curriculum-embedded student reflection and self-assessment, teacher formative feedback and task customization, and end-of-unit summative assessment, with some groups seeking to develop systems where these final assessments have the technical quality required to be part of a state accountability system. A learning management system can generate embedded assessments for teachers and students that indicate the level of additional help students may need and classify students into groups for tailored follow-on off-line reflection activities, which further guide students to use scientific discourse. Since many new media tend to be inherently social, but most existing assessment systems are fundamentally individualized, their use introduces clear tensions and challenges making newly salient questions such as the following: Is it ever possible to gauge individual contributions to fully participatory activities? On the other hand, some scholars are arguing that eventually evidenced centered design combined with modern technologies has the potential to support "seamless" collection of multiple pieces of evidence embedded in ongoing work through an assessment system that would seem so natural students would not realize that it had even occurred.

Assessment involves the making of judgment about the status of student learning against some referent. A number of jurisdictions have developed standard-based criteria to be used to judge student acquisition of a particular level of accomplishment in the different aspects of the inquiry process. Similar criteria/rubrics are being developed to assist teachers in making decisions about and providing support for student scientific argumentation, modeling, and reasoning. Researchers with an interest in learning progressions, initially focused on content areas such as the nature of matter and evolution, are now turning to investigate the development of student competency in inquiry practices as these might be activated, developed, and expressed over a variety of contexts. To date these researchers have taken the grain size of a learning progression to be a single aspect of inquiry, such as mechanistic reasoning, modeling, and coherence seeking, while acknowledging that progress in one aspect of inquiry may be inextricably linked to progress in others. This work can be expected to have substantial implications for large-scale and classroom assessment of students doing science in terms of teacher expectations for and guidance of student learning and for student monitoring and action on their own learning progress.

Where and When to Assess the Doing of Science

The current imperative that school science prepares students to use and continue to learn science throughout their lives poses a substantial challenge to the robust assessment of students doing science. This challenge relates to how student knowledge construction, critique, and use over time and out of the classroom/school and into their future might be captured and documented. Implicitly it requires that assessment tasks, like learning tasks, have value, meaning, and traction beyond the classroom. Grounding assessment tasks in a real-life context, as discussed above, goes someway towards addressing this issue. So too do attempts to require students to show that they can apply their skills, knowledge, and understanding in "unfamiliar contexts." Other options for addressing this challenge include students demonstrating or presenting what they know and can do to an audience beyond the teacher, and sometimes beyond the rest of the class. This could involve students writing storybooks for younger children which they then read to younger students; students preparing posters or constructing local environmental impact statements which are publically displayed and/or sent to interested members of the community; a class preparing and presenting what has been learned to a school assembly to which their families are invited; or staging a mock public debate for which they collect and marshal evidence to support a point of view. In these instances students need to focus on the demands and indicators of success of real-life audiences. Optimally, students' sharing and demonstration of knowing result in learning and/or action of benefit to others. In the case of the last two examples, parents gain a more direct insight into what their child knows and is capable of. In yet other studies students have been involved in community-based projects in which, although student learning is often still assessed via conventional means, evidence of what has been learned is embedded in the class contribution to the community. Examples of this type of instruction and assessment tend to revolve around environmental issues such as water monitoring.

Concluding Comments

Assessment practices are part of a multilayered interactive system in which curriculum, pedagogy, and student and societal expectations and experiences all exert an influence. What it means to do science has expanded from a focus on practical skills to science-informed action. New pedagogical approaches in support of these goals are being developed. The challenge remains to develop assessment at all levels of the system that will complement these expanded goals and help make the learning process and what has been learned visible to learners and other interested stakeholders.

Cross-References

- ▶ Argumentation
- ▶ Assessment of Knowing and Doing Science
- ▶ Inquiry, Learning Through
- ▶ Laboratory Work, Forms of
- ▶ Laboratory Work: Learning and Assessment
- ▶ Multimodal Representations and Science Learning

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Assessment of Knowing and Doing Science

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The essential function assessment serves is the measurement of students' science knowledge and abilities at a moment in time. Data from the measurement answer the question: What do students know and what are they able to do? The simplicity of the question belies the challenges posed when interpreting data that answer the question.

What do students know? The breadth of scientific knowledge and differences in the depth to which it can be known contribute to the complexity of possible answers. The PISA 2009 Assessment Framework distinguishes two categories of science knowledge, knowing of science and knowing about science. Knowledge of science includes knowing the fundamental concepts, principles, laws, and theories of the physical, life, and Earth and space sciences. Knowledge about science includes knowing the modes of inquiry, philosophical perspectives, and history of the natural sciences. Because the development and practice of the natural sciences is closely aligned with technology and engineering, knowing of and knowing about technology and engineering are components of science knowledge included in assessment. The breadth and diversity of science knowledge contributes to the complexity of answers to the question, what do students know.

Depth of knowledge is also confounding factor. In the literature of science education, a distinction is made between just knowing something, a principle for instance, and understanding it. However, the essential characteristics on which the distinction is based are seldom described. Because depth of knowledge is weakly conceptualized, the nature of the empirical evidence from which valid conclusions regarding depth of knowledge can be made is difficult to describe. Consequently, interpretation of data describing what students know is challenged by knowing the depth to which students know it.

What are students able to do? Skills, abilities, and practices are generic terms used to answer this question. Science skills, abilities, and practices are extensive in number and related to diverse activities including the design and conduct of inquiries; the construction of science explanations and arguments, and the reasoning modes applied in the natural sciences. The breadth and diversity of science skills, abilities, and practices contributes to the complexity of answers to the question.

While claims are made that certain assessment tasks are exclusive measures of what students know and others exclusively measure what students can do, in fact, every assessment task measures both knowing and doing. Students' knowledge, skills, abilities, and practices are inferred from observations of actions or products of action. The action may be as simple as penciling in the circle next to the correct response to a factual question, such as how many bones are in the human body. Even simple tasks such as demonstrating knowledge of a fact require generic skills including reading and following directions. More challenging tasks such as writing an explanation of an observation require generic skills, science knowledge, and science-specific abilities. If the action, writing, produces an explanation that has the characteristics of a scientific explanation, we infer that the student knows the characteristics of scientific explanations and has the ability to apply that knowledge to write an explanation. The explanation is also evidence of the student's knowledge of the science principles relevant to the phenomena observed and the student's ability to apply that knowledge appropriately. Generally the appropriate application of science principles is considered evidence that the principle is understood rather than just known.

The breadth and complexity of scientific knowledge and abilities and their interaction make interpretation of data that answer the question what do students know and what are they able to do challenging. This challenge is particularly relevant when attempting to compare data from different assessments. Absent detailed information about the knowledge and abilities measured comparisons may be spurious.

Cross-References

- ▶ Assessment of Doing Science
- ▶ Assessment of Knowing Engineering and Technology and Doing Engineering and Technology: Overview
- ▶ Cross-Disciplinary Concepts and Principles in Science, Assessing Understanding of
- ▶ Inquiry, Assessment of the Ability to

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Assessment of Knowing Engineering and Technology and Doing Engineering and Technology: Overview

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Keywords

Assessment; Concepts; Engineering; Practices; Technology

A variety of meanings have been associated with the terms engineering and technology. The definitions for this entry are based on numerous documents produced by USA sets of experts. The National Academy of Engineering report, *Standards for K-12 Engineering Education?* (NAE 2010), surveyed standard documents in engineering, technology, science, and mathematics to identify common engineering concepts and skills. The National Assessment Governing Board supported the development of the *Technology and Engineering Literacy (TEL) Framework for the 2014 National Assessment of Educational Progress*. The National Research Council of the National Academies has published the *Framework for K-12 Science Education*, which, along with a draft *Next Generation Science Standards*, integrates engineering ideas and practices with those in science (NRC 2012; Achieve 2012). Definitions of engineering and technology can be culled from these frameworks and standards developed by national engineering and science organizations, as well as from standards for engineering and technology for state, national, and international assessments.

The definitions of engineering and technology are the starting points for developing assessments of understanding them. Similarly, conceptualizations of the engineering design process are the starting point for developing assessments of engineering practices that both use and produce technologies. This entry begins with a summary of prominent conceptualizations of engineering and technology and the practices of applying them. The definitions are followed by descriptions of an assessment design framework that can be used to develop and analyze assessments of engineering and technology. Descriptions of some potential types of assessment tasks and items to test understanding and application of engineering and technology are provided.

Definitions of Engineering and Technology

Engineering is defined as a systematic and iterative approach to designing objects, processes, and systems to meet human needs and wants. *Technology* is defined as any modification of the natural or designed world developed to fulfill human needs or desires. Technologies, therefore, are products and processes resulting from application of engineering design processes. Technologies also often function as tools and processes used to support engineering design. In most reports that set forth frameworks or standards for engineering, technology, and science, the three domains are described as related by their focus on systems in the real world, yet different in the roles that the disciplines play in understanding and modifying the world. Engineering and technology often apply science knowledge to meet human needs and desires.

Sources of Conceptualizations of Engineering and Technology

Standards for K-12 Engineering Education?

The purpose of the National Academy of Engineering report was to survey contemporary frameworks, standards, and practices in engineering to determine if a national set of engineering standards could be proposed (NAE 2010). The report summarized key ideas of engineering and recommended that engineering concepts and processes should be integrated into and linked with contemporary frameworks and standards in science, technology, mathematics, and other disciplines. The report identified a set of the most commonly cited core engineering concepts. The central engineering construct was "design" – understanding and doing it. Other important concepts included understanding constraints, understanding systems, and optimization. Central skills included modeling, system thinking, and analysis. In addition, the report emphasized the importance of understanding the relationship of engineering and society and the connections among engineering, technology, science, and mathematics.

Technology and Engineering Literacy (TEL) Framework for the 2014 National Assessment of Educational Progress

The TEL framework is unique in its focus on assessing the interrelationships of engineering and technology. In the framework, technology and engineering literacy is defined as the capacity to use, understand, and evaluate technology as well as to understand technological principles and strategies needed to develop solutions and achieve goals (NAGB 2010). The framework lays out three areas of technology and engineering literacy, the types of thinking and reasoning practices that students should be able to demonstrate, and the contexts in which technologies occur. Three main assessment areas are specified: Design and Systems, Information and Communication Technology, and Technology and Society. Within Design and Systems, three subareas of essential knowledge and skills are identified: nature of technology, engineering design, system thinking, and maintenance and troubleshooting.

Principles for the nature of technology expand the scope of common conceptualizations of technology beyond computers and the internet. The broader view includes every way people manipulate the natural environment to satisfy needs and wants. Therefore, technology includes all the various devices and systems that people make to fulfill some function. The framework lays out key principles for the nature of technology: (1) technology is constrained by the laws of nature; (2) scientists examine what exists in nature and engineers modify natural materials to meet human needs and wants; (3) technological development involves creative thinking; (4) technologies developed for one purpose may be adapted for other purposes; (5) science, technology, engineering, and mathematics and other disciplines are naturally supportive; (6) the pace of technological change has been increasing; and (7) tools help people to do things efficiently, accurately, and safely. The framework then lays out assessment targets for the nature of technology for grades 4, 8, and 12.

The engineering design subarea in the TEL framework is described as an iterative, systematic process for solving problems. These processes are among the practices of engineering. The process begins with stating a need or want and identifying the criteria and constraints of the challenge. Then, potential solutions are explored referencing relevant scientific and technical information. Potential solutions are compared, and models and prototypes are constructed, tested, and evaluated to see how they meet the criteria and constraints of the problem. Two additional components of Design and Systems are system thinking and maintenance and troubleshooting. System thinking is a way of thinking about devices and situations so as to better understand interactions among system components, root causes of problems, and the consequences of various solutions. Maintenance and troubleshooting is the set of methods used to prevent technological devices and systems from breaking down and to diagnose and fix them when they fail. For each of these Design and Systems components, assessment targets for grades 4, 8, and 12 are presented.

The framework also specifies components, principles, and assessment targets for grades 4, 8, and 12 for the pervasive technology area of Information and Communication Technology (ICT). ICT is presented as a separate assessment area within technology and engineering literacy because of the central place ICT plays in learning and functioning in school, the workplace, and daily living. ICT sub areas to assess include understanding and use of technologies for (1) construction and exchange of ideas and solutions, (2) information research, (3) investigation of problems, (4) acknowledgment of ideas and information, and (5) selection and use of digital tools. Assessment targets for ICT at grades 4, 8, and 12 are presented.

The assessment area of Technology and Society addresses the effects that technology has on society and on the natural world and the sort of ethical questions that arise from those effects. The area is further divided into interaction of technology and humans, effects on the natural world, effects on the world of information and knowledge, and ethics, equity, and responsibility. Assessment targets for grades 4, 8, and 12 are presented.

The TEL framework also describes three crosscutting practices: understanding technological principles, developing solutions and achieving goals, and communicating and collaborating. The framework provides numerous examples of how these practices apply to the Design and Systems, ICT, and Technology and Society areas.

Framework for K-12 Science Education and the Draft Next Generation Science Standards

The framework includes engineering and technology as they relate to applications of science (NRC 2012; Achieve 2012). Engineering is used to mean engagement in a systematic design practice to achieve solutions to particular human problems. Technology is used to include all types of human-made systems and processes. Two core engineering ideas are specified. The first is engineering design – how engineers solve problems. The second core idea is understanding the links among engineering, technology, science, and society. Engineering design is subdivided into three components: (1) defining and delimiting a problem, (2) developing possible solutions, and (3) optimizing the design solution. Links among engineering, technology, science, and society are partitioned into (1) interdependence of science, engineering, and technology and (2) the influence of engineering, technology, and science on society and the natural world. The framework describes grade band end points for each of the three components.

The framework also describes the key practices that scientists use as they investigate and build models and theories about the world and the key engineering practices that engineers use as they design and build systems. Science and engineering practices include asking questions and defining problems; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics, information and computer technology, and computational thinking; constructing explanations and designing solutions; and engaging in argument from evidence. The framework describes grade band end points for these practices.

The draft *Next Generation Science Standards* provide more specific guidance for assessing engineering design that produces and uses technology. Performance expectations are presented for the engineering design components. The performance expectations integrate the engineering core ideas with cross-cutting concepts such as systems and models and cause and effect and also with science and engineering practices.

Each of the frameworks and standards described above can serve as resources for specifying the engineering and technology concepts and practices to assess. In the following section, the use of a systematic assessment design framework is presented to support the selection or development of assessments.

Assessment Design

The focus of this entry in the encyclopedia is on methods for assessing understanding of engineering and technology and the practices for applying the engineering design process and the technologies that both can support the design processes and are a result of them.

Assessment Purposes

The selection or development of assessments will depend on the purposes of the assessments and the planned interpretations of the data. An assessment may be intended to provide diagnostic feedback and be used in a formative way to allow adjustments during instruction to improve performance. Or, assessments may be intended to provide summative information about proficiency levels of knowledge and skills following courses or projects.

Formative Assessments

Assessments intended as formative feedback for students and teachers about progress on learning outcomes can be embedded throughout learning activities in extended projects. The more extended the project, the more opportunities will be available to build in ongoing assessments and to adjust instruction. Ideally, the design of both the learning activities and assessments would occur simultaneously, stimulating iterative cross-checking that the learning activities are designed to directly promote all the specified engineering and technology knowledge and practices, that systematic assessments of progress on all these targets are planned, and that provisions for scaffolding and instructional adjustments can be made.

Learning progressions may guide the sequence of assessments within learning activities and be linked to types of common misconceptions or ineffective problem-solving and inquiry strategies. Careful analyses from embedded formative assessments of the unfolding conceptual and problem-solving development planned throughout a project can allow in-depth attention to problem-solving practices ranging from design and prototyping to communication of solutions. Assessments of the particular engineering and technology knowledge and strategies can be made “just in time” as students are applying the concepts and in the process of engaging in the practices. Extended engineering projects offer opportunities to assess more knowledge and practices, more often, and in more depth.

Summative Assessment

An assessment may be intended to serve a summative purpose to report on the status of proficiency at a point in time. Summative assessments may be administered at the end of a project or course or at end points such as units or project phases. These purposes will have implications for the criteria used to select, design, or interpret assessments.

Evidence-Centered Assessment Design

A useful framework for understanding the structure and functions of assessments is evidence-centered assessment design (Mislevy et al. 2004). Evidence-centered design is intended to structure an assessment argument. The argument begins with the claim that specified knowledge or skills have been learned. Evidence to support the claim comes from the types of questions or tasks that will elicit observations and performances of the targeted knowledge or skills. Summaries of performances, typically in the form of scores to be reported and interpreted, then are used as evidence to complete the argument. Therefore, evidence-centered assessment design tightly links the targeted knowledge and skills (student model), with assessment tasks and items to elicit evidence of these targets (task models), with specifications of how the evidence will be scored and analyzed to report proficiencies (evidence model). The evidence-centered assessment design framework can be used to analyze and evaluate existing assessments of the knowledge or practices targeted or to guide the systematic development of new ones.

The essential first step will be to settle on the definitions of engineering and technology – the specific knowledge about them and practices to be tested. These knowledge and practice targets would become the first component of the student model. A second component of the student model would be the cognitive demands or levels of reasoning required. Cognitive demands could range from identifying definitions and examples of the concepts and practices to analyzing descriptions of the technology and engineering concepts and practices in a project as it unfolds to evaluating others' use of the technologies and engineering design practices.

The engineering design process creates plans for developing solutions. Solutions may be tangible artifacts or technologies, such as digital devices or farm machinery. Solutions may also be new or improved technological processes such as more efficient manufacturing procedures or pharmaceutical clinical trials. These solutions are *technologies* that have been developed to address needs in areas of the designed world such as medicine, agriculture, energy, transportation, manufacturing, and construction. ICT projects may set goals to be achieved by use of multimedia resources. Students tend to think of technology in terms of computers and digital technologies, not in terms of the artifacts and solutions engineered in the many other areas of the designed world. Students are expected to understand that there are technologies in all these areas, from pills, plows, plugs, planes, and pinions to pickup trucks. Specifications of the knowledge to be tested will need to decide what students need to understand about the engineering processes, the role of technologies in them, and the technology products. Statements of what the student needs to know and the level of reasoning for showing it will become the assessment targets of the student model.

The task model(s) for an assessment specifies the kinds of contexts, problems, and items that would elicit evidence that the students understood the engineering design and technology ideas and concepts and could use them to solve problems and achieve goals. Simple items could ask for students to identify concepts and components of an engineering design project and the technologies used and produced. Descriptions of needs addressed by an engineering project producing solutions could include questions to determine that students understood that the solutions, whether new tools or new processes, are technologies. At stages in the design process, students could respond to questions and post work samples to demonstrate that they were able to apply the design concepts and processes.

Types of embedded assessment tasks and questions can vary. Conventional question formats can be inserted to check for basic knowledge. Tasks that ask students to document their work in progress may include entries in design notebooks and periodic submissions of interim material such as sketches, prototypes, pilot test data, and presentations.

Tasks and items can be designed around scenarios presenting engineering design problems and/or ICT goals in a range of applied contexts. The overarching problem could be to select and construct engineering processes to use in attempting to solve the problem. Within tasks could be inserted questions about the appropriate supporting technological tools to use and about the resulting solution as a technological advance.

The SimScientists program at WestEd has developed simulation-based models of systems to assess understanding and use of science and engineering practices (Quellmalz et al. 2012b; http://simscientists.org). As shown in Fig. 1, a scenario was developed in which students are working to establish a sustainable research center in Antarctica. By harnessing available sunlight and wind, scientists at the station are able to generate electricity, which can be used for the electrolysis of water, which in turn results in the production of hydrogen gas. The simulation-based assessments have been designed to assess core ideas about atoms and molecules, changes in state, properties of matter, and the science practices of designing and conducting investigations. The scenario could be adapted to also assess engineering and technology by augmenting the scenario with sets of tasks about the design, testing, and troubleshooting for an energy production, conversion, and storage system that contributes to a sustainable research center.

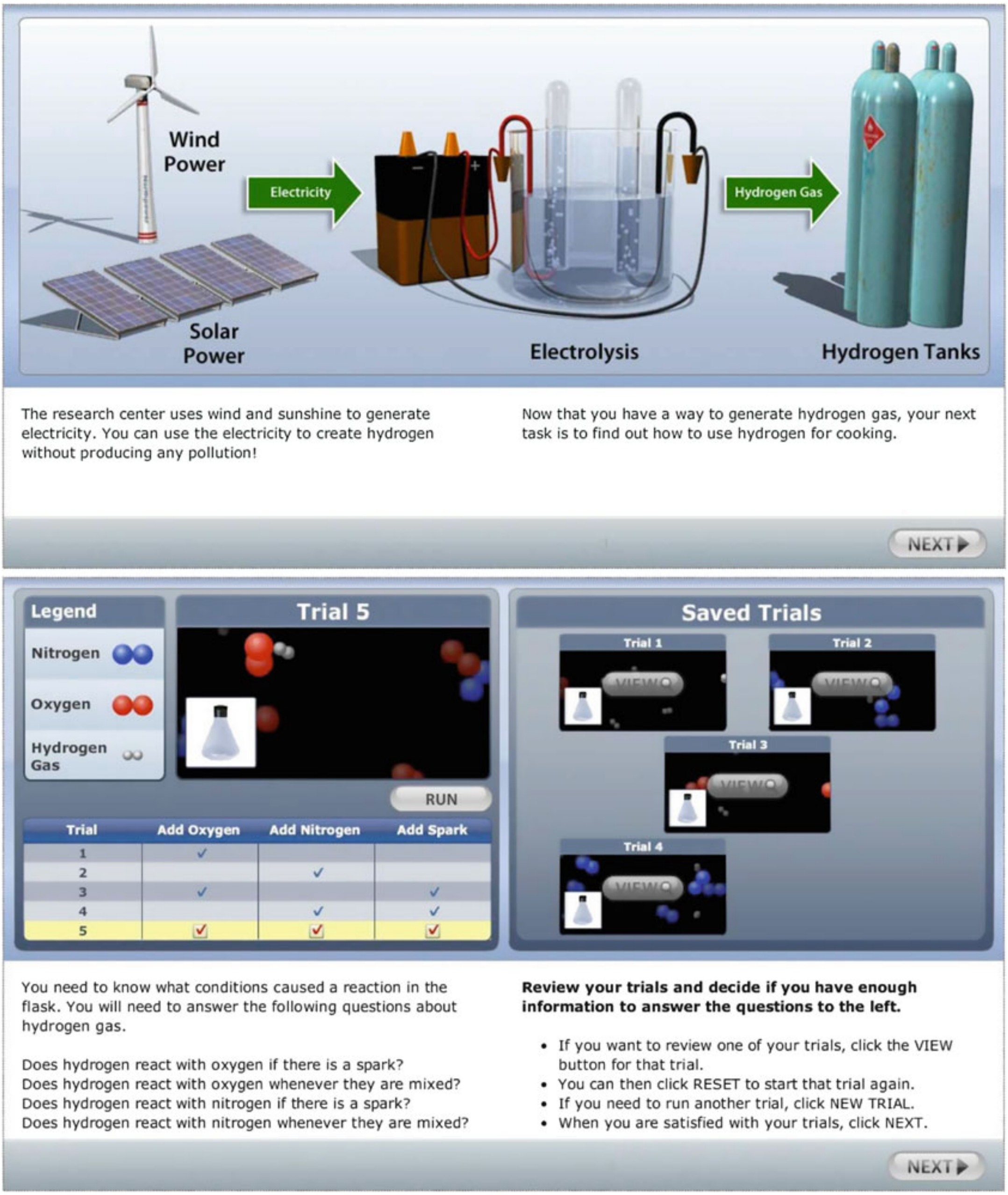
As foundational computer models of systems, natural and man-made, are developed, they can support the development of tasks to assess engineering, technology, and science concepts and practices and also to assess twenty-first-century skills such as communication and collaboration (Quellmalz et al. 2012a). For example, students could be asked to construct descriptions for the Antarctic Research Center Board for a proposed sustainable energy plan or to critique if solutions proposed by others meet the design constraints. A virtual collaborator could be queried to seek relevant information about the trade-offs of alternative sustainable energy treatments.

Final project artifacts and presentations can be used in summative assessments of specific engineering projects or performance assessment events. Rubrics for evaluation of the performances, artifacts, and exhibitions should go through standard assessment development procedures and technical quality screening for reliability and validity (AERA/APA/NCME 1999). Project-specific reports should interpret evidence on all targeted knowledge and practices. Postings of portfolios of final projects and explanations of how they meet criteria can serve as examples of successful performance.

Summative assessments of student learning should carefully align tasks and items in existing or newly developed measures with all the knowledge and practices claimed to be benefitted by prior learning activities. A custom-made summative assessment for a particular project or curriculum should provide an alignment document describing the links between the assessment tasks and items and the targeted engineering and technology standards. Studies of the technical quality (reliability and validity) of these project-specific summative assessments should be conducted and documented (AERA/APA/NCME 1999).

Design of Large-Scale, Cross-Program Summative Assessments of Engineering and Technology

Claims for the effects of multiple engineering and technology programs on learning will need to carefully align the scope of the claims to the scope of the learning outcomes. One approach is to analyze program effects on learning by examining performance on separate tests of engineering and technology. Existing large-scale assessments in the separate disciplines, such as district, state, or national tests, will only be aligned with some of the intended outcomes in one discipline, let alone in multiple disciplines. A large-scale technological literacy or science test, for example, will test a broader range of content than any one engineering or technology program would claim to affect. Moreover, problem-solving and design practices do not tend to be well measured by conventional item formats prevalent on most large-scale tests. A specific program, curriculum, or project can compare student performance on targeted



The research center uses wind and sunshine to generate electricity. You can use the electricity to create hydrogen without producing any pollution!

Now that you have a way to generate hydrogen gas, your next task is to find out how to use hydrogen for cooking.

Trial	Add Oxygen	Add Nitrogen	Add Spark
1	✓		
2		✓	
3	✓		✓
4		✓	✓
5	☑	☑	☑

You need to know what conditions caused a reaction in the flask. You will need to answer the following questions about hydrogen gas.

Does hydrogen react with oxygen if there is a spark?
Does hydrogen react with oxygen whenever they are mixed?
Does hydrogen react with nitrogen if there is a spark?
Does hydrogen react with nitrogen whenever they are mixed?

Review your trials and decide if you have enough information to answer the questions to the left.

- If you want to review one of your trials, click the VIEW button for that trial.
- You can then click RESET to start that trial again.
- If you need to run another trial, click NEW TRIAL.
- When you are satisfied with your trials, click NEXT.

Assessment of Knowing Engineering and Technology and Doing Engineering and Technology: Overview, Fig. 1 SimScientists simulation-based assessment

standards to results of an entire math, science, engineering, or technology test, or to subsets of items within each test that are directly aligned with the targeted knowledge and practices. The more closely aligned program-specific engineering and technology targets are with subsets of items within a large-scale science, engineering, or technology test, the more likely program effects will be detected by analyses of performance on these aligned item clusters.

Preferably, large-scale, summative assessments would be especially designed to measure engineering and technology learning within applied problems and contexts. Scenario-based assessment tasks could set up relevant, applied, real-world challenges. For instance, students could be asked to address design problems related to the use of wind turbines in an urban area. Task and question sets related to the scenarios would tap key concepts and practices for engineering and technology. Students could be asked to design a study about amounts of wind or sunlight in different areas of the city, to compare the benefits of alternative wind turbine designs, to evaluate environmental effects such as dangers to birds, and to then analyze and report the data.

The evidence model for an assessment would involve determining what kind of scoring and reporting would convey that the student understands the engineering and technology conceptual targets and their application in applied problems. Scoring rubrics are commonly developed to evaluate these variable and open-ended performances and artifacts. The rubrics for specific assignments should derive from more broadly accepted criteria in the field for the quality of work as indicated by its appropriateness, breadth, and depth. The challenge is to develop criteria that relate to general quality features, but that can be clearly applied to the specific project's problem. The rubrics should be usable by students as well as teachers. Practice using the rubrics and checking that multiple users apply them consistently are fundamental elements of sound assessment practice. Moreover, in a balanced assessment system, criteria for rubrics for classroom-level, project-specific activities would be criteria also applied in summative performance assessments. Therefore, criteria would apply to effective use of engineering and technology concepts and practices, rather than to unique information about the design of a bus or an airplane wing. Monitoring and recording formative progress assessments is recommended for comparing project-specific performance on assessment targets to performance on summative measures. Specific reports about the conceptual and practice assessment targets would be needed.

The assessment selection or development process can use the framework of evidence-centered assessment design framework to guide analyses of existing tasks and items or to guide the development of new, appropriate tasks and items. The framework would ask if the knowledge to be tested and practices are clearly specified (student model) and if the tasks and items will provide evidence of conceptual understanding and application, perhaps in a range of applied areas such as ICT, agriculture, medicine, and manufacturing (task model). The framework would also ask if the scoring and reporting clearly allowed decisions to be made about whether the understanding of the targeted concepts of engineering and technology and the use of the practices are sufficiently strong (evidence model). The decisions could then be used as formative assessments that would diagnostically inform further instruction or as summative assessments to support a proficiency report. The key to sound assessment is that the assessment argument is clear and supported.

Cross-References

- ▶ Assessment: An Overview
- ▶ Engineering and Technology: Assessing Understanding of Similarities and Differences Between Them
- ▶ Engineering, Assessing Understanding of
- ▶ Engineering Design, Assessing Practices of
- ▶ Science and Technology
- ▶ Science, Technology, and Engineering Interrelationships: Assessment of the Understanding of
- ▶ Technology, Assessing Understanding of
- ▶ Technology Education and Science Education

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Assessment Specifications

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Keywords

Assessment specifications; NAEP; PISA; TIMSS

Assessment specifications refer to the design of a plan that is used to develop the assessment indicating the main features to be covered. They identify the topics and skills to be tested and the emphasis given to each category. Also, they document the student population to be assessed, test booklets' design, question types, constructed-responses scoring, and achievement reporting and provide samples of items. The released examples from previous cycles are offered to illustrate how the learning acquisitions are measured and also to present a range of response formats and coding and scoring features. The role of the specifications is to provide a foundation of terms, processes, and procedures so that all involved with the development or consumption of assessment results may operate from a common understanding. They represent the first step to take for constructing the assessment being continually reviewed and modified to reflect the current state of knowledge.

For example, Programme for International Student Assessment (PISA) 2009 is administered to 15-year-olds. The specifications include information about the tested domains in that cycle – reading is the major domain and mathematics and science are minor domains. For the paper-based assessment, there are 37 reading units comprising 131 cognitive items, 18 mathematics units with a total of 34 items, and 18 science units with 53 items. The item formats are either selected response multiple choice or constructed response. The items are organized in units around a common stimulus – passage text, table, graph, or diagram setting out a real-life situation. Items have to be developed with respect to the major framework variables defined for each tested domain – text type variable, text format variable, situation variable, and aspect variable (for the reading domain); competency and content category (mathematics domain); and competency and knowledge type (science domain) – and have to represent a wide range of difficulties. Their distribution across categories is also provided. The items are allocated to 13 clusters (seven reading clusters, three mathematics clusters, and three science clusters). The items are assembled in 13 standard test booklets; each booklet is composed of four clusters according to a rotated test design, each cluster representing 30 min of testing time. Each student is randomly assigned 1 of the 13 booklets administered in each country. Student responses in all participating countries and economies are scored following certain procedures. The coding scheme is developed to enable markers to code the student responses in a consistent and reliable manner. Codes are applied to test items, either automatically capturing the alternative chosen by the student for a multiple-choice item or by an expert judge selecting a code that best describes the response given by a student to an item that requires a constructed response. The dichotomous scoring provides full credit or no credit. Partial-credit scoring is used for some of the more complex constructed-response items. Such items scored polytomously receive full-credit score, one or more partial-credit scores, or no-credit score. The code, of either type, is then converted to a score for the item. The students' scores are represented on a common achievement scale using item response theory methods that provide an overall picture of the assessment results for each country (OECD 2012).

Trends in International Mathematics and Science Study (TIMSS) assesses the mathematics and science achievement of students in their fourth and eighth years of formal schooling. The assessment specifications identify the content and cognitive domains for the TIMSS fourth- and eighth-grade assessments and their percentages in the testing time for both mathematics and science. The entire assessment pool of items at each grade level is packed into a set of 14 achievement booklets, each item appearing in two booklets. There are 28 item blocks: 14 mathematics blocks and 14 science blocks. Each block groups approximately 10–14 items at the fourth grade and 12–18 items at the eighth grade. The assessment time is established to 72 min for fourth grade and 90 min for eighth grade. Two-item formats are employed: multiple choice and constructed response. The format that best enables students to demonstrate their proficiency determines the choice of item format. The students' responses at constructed-response items are scored using the scoring guide. In the scoring guide the essential features of appropriate and complete responses are described. The focus is on evidence of the type of the cognitive process the question assesses. Each descriptor is accompanied by examples of partially correct and fully correct responses and incorrect answers. Each multiple-choice question is worth one score point. Constructed-response questions are generally worth one or two score points. Reporting scales are available for each content and cognitive domain in mathematics and science at each grade level (Mullis et al. 2009).

Cross-References

- ▶ Assessment: An Overview
- ▶ National Assessment of Educational Progress (NAEP)
- ▶ Programme for International Student Assessment (PISA)
- ▶ Scale Scores
- ▶ Third International Mathematics and Science Study (TIMSS)

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Assessment to Inform Science Education

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Keywords

Accountability; Data-driven decision making; Formative assessment; Proximal formative assessment; Summative assessment; Validity

Assessment in science education, like other disciplines, is evolving into measures designed so that they can be used to inform instruction and learning, not be used just for accountability purposes. It is essential that instruction and assessment be linked and form a feedback loop in which assessment results inform instructional decisions, but the assessments must be closely aligned to the instructional objectives in order for this to happen. The tighter the feedback loop, the more instructionally relevant the data become. The longer the delay, the less useful the data will be for instructional purposes. For example, state accountability testing often occurs in the spring and results are delivered to educators for the following academic year. There are two major issues here. First the test may not be sufficiently aligned to the educational objectives. Second, the duration between testing and delivery of the results may render the data less than useful. Such data are referred to as autopsy or dead-on-arrival data. What may differ for science, as opposed to content areas such as English language arts and mathematics, is that science is not always tested for state accountability purposes. There still may be summative science assessments, but just not for high-stakes purposes.

Another issue centers around the issue of validity. Validity is often seen as a property of the assessment; that is, does the assessment measure what it purports to measure? Another view is that validity resides in the interpretation made on the results. Assessments used for accountability may be designed to provide an estimate of how well students have mastered a particular content area, such as biology or chemistry, but they may not be designed in a manner that can provide teachers with the grain size of data that can inform instruction. Such tests may provide total test scores or subscores but may not allow teachers to drill down to specific content or even items to enable diagnoses of learning deficits. Thus, these tests may be valid as summative measures, but less valid for instructional purposes.

A trend that has gained traction centers around formative assessment. Whereas summative assessments are seen as measuring the culmination of learning on a specific unit, topic, or course, formative assessments are seen as more closely tied to instruction, helping teachers to understand students' learning strengths and weaknesses so that further instructional steps can be identified (see Black and Wiliam 1998; Bennett 2011). Stiggins (2005) differentiates between assessments *for* learning and assessments *of* learning. Assessments *of* learning are seen as summative indicators of what students have learned and are typically used for accountability purposes, whereas assessments *for* learning provide indications of what students have learned or not learned so that the information can help to drive instruction. These assessments have different purposes, and therefore different kinds of interpretations can be made from them. The most instructionally valid measures are assessments *for* learning. Formative assessment is a process, not just a measure (Bennett 2011). They are designed to be used by teachers to directly inform their instructional practice. The feedback loop between instruction and assessment is tight. Assessment is conducted in real time. Erickson (2005) refers to this as "proximal" formative assessment.

A major threat to the use of formative assessments, as Erickson (2005) notes, is whether teachers know how to interpret the results and link them to "pedagogical moves." This is what Mandinach (2012) refers to as pedagogical data literacy and what Means et al. (2011) call instructional decision making. A key skill for teachers is their ability to take data from an assessment, classroom activity, or project, understand what the students know and don't know, and then transform those data into actionable instructional steps. This skill is one that is not well addressed in typical professional development around data-driven decision making (Mandinach and Gummer 2012). It may, however, be a component of training around formative assessments. Thus, for science and other disciplines, assessments to inform instruction rely not only on test design, but also on the duration of the instructional/assessment feedback loop and teachers' ability to interpret the data in ways that allow them to transform the results into actionable instructional knowledge.

Cross-References

- ▶ Evidence-Based Practice in Science Education
- ▶ Evidence-Informed Practice in Science Education
- ▶ Formative Assessment
- ▶ Test
- ▶ Validity and Reliability of Science Assessments

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Assessment: An Overview

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Assessment involves the collection of information to be used in making decisions. Some assessment information is used to describe the status quo, some to measure change, and some to make comparisons. Ultimately, however, the information is applied to making decisions. The decisions range from those having immediate effects on individual students to those having long-term effects on all of a nation’s students or on large populations of students within a nation. Few if any of the decisions are made on the basis of information alone. Philosophical, political, economic, and theoretical factors influence decisions and may override the information relevant to making the decision.

The importance of data in making educational decisions has global dimensions and is characterized by ever-increasing expenditures by nations on the design and implementation of **assessment systems**. At the classroom level there has been an increase in professional development for teachers to develop their abilities to design classroom measures that yield information, enabling them to make good instructional decisions and to use data from external assessment to facilitate their educational decision making.

Information/data is collected by individuals (students, teachers, principals, and administrators), by agencies with jurisdiction over a country, by agencies with jurisdictions over segments of a country, and by independent organizations formed by cooperative agreements among nations. Examples of independent organizations responsible for cross-national assessment are the International Association for the Evaluation of Educational Achievement (**IEA**) which oversees the design and implementation of **TIMSS** (Trends in International Mathematics and Science Study) and the Organization for Economic Co-operation and Development (**OECD**) which oversees the design and implementation of **PISA** (**Programme for International Student Assessment**).

The information/data from assessments is used to make many different kinds of decisions. The information that may have the most profound impact on student learning is that gathered by students as they either consciously or intuitively become aware of their own knowledge and abilities and how these match with the expectations of their science teachers and parents. Helping students systematize their **self-assessment** abilities is a goal of science education. Information/data collected by teachers is used to make instructional, grading, and promotion decisions. **Formative assessment** is used to describe information collection and analysis resulting in information used by teachers to make decisions regarding instructional practices related to materials and pedagogical strategies for their classes and for meeting the particular instructional needs of individual students. **Summative assessment** is used to describe the collection of information to be used to grade students and to make decisions regarding promotion.

Instructional, grading, and promotion decisions are based not only on information collected by teachers. Data from external assessments administered by countries and regions within countries are sometimes used to evaluate the effectiveness of educational materials and strategies, to determine grades, promotion, and future educational opportunities for students. (Insert examples here for several counties.)

Data/information about student performance from regional or country-wide assessments is sometimes used to make decisions regarding teacher compensation and placement in schools.

Data from assessments tracking performance over time or comparing the performance of students in different countries or regions often stimulate and inform policy development at the country or regional level. The United States' National Assessment of Educational Progress (**NAEP**) is an example of a nationally mandated assessment that influences educational policy at the national level. Examples of country wide science assessments include the German Abitur, the Israeli Bagrut, and New Zealand's National Education Monitoring Project (NEMP).

The posited relationship between the strength of a country's education system and that country's economic strength is the origin of interest in cross-national assessment activity and educational policy development aimed at preparation for the workplace and higher education. Comparisons of student performance on national assessments with performance on TIMSS and PISA are highly influential in national policy discussion. Consequently student performance on these assessments is **high stakes**.

Typically, the information collected by teachers describes that which students know about science and those science-related abilities that students are able to perform. This knowledge and these abilities are closely aligned with the objectives of the science curriculum students are experiencing. **Larger-scale** assessments collect more extensive information including information about students' science knowledge, abilities, and **attitudes** toward science, as well as background information about students (gender, socioeconomic status), science teachers (years of experience, academic preparation, favored instructional strategies), and opportunity to learn science (per-pupil expenditures, science instructional materials, science laboratory facilities, and Internet and computer access).

Science knowledge and abilities have many components. Among the topics students are expected to know about or to understand are scientific theories, principles, and concepts; cross-disciplinary principles and concepts; the nature of science; the history of science; the interrelationships of science, technology, and engineering; and the interactions of science and society. Among the abilities students are expected to develop are **inquiry** (**enquiry**), **communicating science ideas** (**explanation**, **argumentation**), and **self-evaluation**. Not all components of science knowledge or all abilities (skills) are assessed on all large-scale assessments. Some components, attitude toward science, for instance, are included in the main assessment of some assessments (PISA, for instance) and in the background information of others (NAEP, for instance).

Large-scale assessments are challenging to design. Typically a consensus process is engaged to determine the science content that will be assessed and background information that will be collected. The results of the consensus process are presented in a document, often referred to as the **assessment framework**. Either in the framework or in a separate **specifications document**, details of the assessment are described. The specifications include the relative emphasis the different components of science knowledge and understanding will receive, the kinds of items (selected and constructed response items, hands-on) that will be used, and the content of the background material that will be surveyed.

Time is a major constraint on the translation of the framework and specifications into the operational assessment. The student time available for responding to assessment tasks and teacher/administrator time available to respond to background questions is limited, constraining the breadth of content and background information that can be measured.

Including students with special needs and language learners is a challenge to ensuring that an assessment adequately samples the population of interest. Extensive testing in **cognitive laboratories** of assessment tasks to determine the **cognitive demands** of the tasks and language characteristics that make items difficult to understand is an essential part of the development of assessment instruments. Providing **testing accommodations** and **adaptive testing strategies** are approaches to implementation of the assessment to ensure that special needs and language are not preventing students from demonstrating their science knowledge and abilities.

Reporting the results of large-scale assessments is challenging involving the definition of various levels of student performance (**achievement levels**) and showing the relationship of the achievement levels to the tasks which students performing at each level successfully perform. Task performance is typically translated statistically to **scale scores** and achievement levels defined by locations on the scale (**cut scores**).

The quality and relevance of assessment information to possible decisions is a central issue in the decision-making process. In large-scale assessments statistical considerations influence the quality of the data. The characteristics of the population sampled, sample size, constructs measured, the way in which constructs are measured, instrument administration, methods of data reduction, and analysis ultimately determine the statistical quality (**validity and reliability**) of data collected no matter the decision under consideration.

In addition to statistical quality, the match of the constructs measured to the decisions under consideration determines the relevance of the information (data). If, for instance, the decision is to choose which of two science curricula to implement, data comparing differences in students' scores on a standardized mathematics assessment is poorly matched to the decision under consideration. Ultimately, evaluation of the quality of assessment information/data and its use in decision making requires consideration of the question: does the quality of the information warrant the decision made?

Cross-References

- ▶ Assessment of Doing Science
- ▶ Assessment of Knowing and Doing Science
- ▶ Assessment of Knowing Engineering and Technology and Doing Engineering and Technology: Overview
- ▶ Formative Assessment
- ▶ Large-Scale Assessment
- ▶ Programme for International Student Assessment (PISA)
- ▶ Scale Scores
- ▶ Student Peer Assessment
- ▶ Student Self-Assessment
- ▶ Summative Assessment
- ▶ Third International Mathematics and Science Study (TIMSS)
- ▶ Validity and Reliability of Science Assessments

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Assessment: PISA Science

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Keywords

Measures

The assessment of the science component of the OECD's PISA project introduced a radically new intention for the assessment of science learning and operationalized this with a novel instrument that included item types that had not previously been used in such large-scale testing, either nationally or internationally.

The OECD's commission for the PISA project in 1998 was to provide information to participating countries about how well prepared their 15-year-old students were for twenty-first-century life in the domains of reading, mathematics, and science – an unusually prospective brief for the assessment of learning. Fifteen-year-old students were chosen because in a number of countries, it is the age when compulsory study of science and mathematics can cease.

This commission required PISA Science to be not another retrospective assessment of students' science learning, as is customary at the levels of classroom, school, regional, national, and international assessments (like those used by the IEA in its ongoing TIMSS project). Such testing is closely tied to the intended curriculum for science and can be used to indicate a student's readiness to progress to the next level of schooling or to further study of the sciences beyond schooling in universities or other tertiary institutions.

Future preparedness for life in society as an assessment intention was quite unknown in 1998 among the OECD countries. There were, thus, no existing models for such testing, and the one had to be developed that would lead to measures of the students' capability to apply their science knowledge to twenty-first-century contexts involving science and technology (S&T).

This innovative intention to measure preparedness was applauded and endorsed by the member countries of the OECD, but there was widespread skepticism about what would be found by such a study, since the application of science knowledge in unfamiliar contexts was not something that existing science education in schools was emphasizing. It was encouraging that the students in many countries performed well on the tests although there was clear scope for improvement in all cases.

Future Preparedness as a Goal for Science Learning

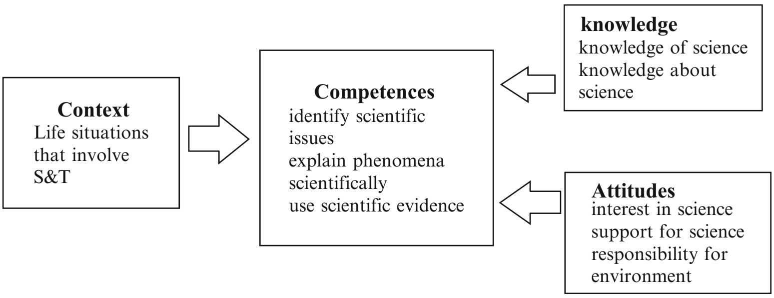
It is quite common to find the science content knowledge for teaching and learning listed in a curriculum's statement under a dual heading of knowledge and understanding. It is as if these two words are synonymous, since there is usually no explanation that they may be intended to refer to different learning of the same content from shallow recall to deeper application.

When this difference was made explicit, the countries interested in PISA Science suggested that it would primarily measure how well their students can apply the science knowledge they have learned to novel S&T contexts and hence go beyond the simple recall and application of the science as it is taught or presented in textbooks.

The organization of PISA meant that science was a minor domain in PISA 2000 and 2003, so that the Science Expert Group had the opportunity to explore several approaches to its task before settling on a framework that would deliver a defined goal for student achievement in 2006 when science was the major domain. The framework is presented in Fig. 1.

The goal was a measure of students' scientific literacy defined as an individual's:

- Scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues



Assessment: PISA Science, Fig. 1 Framework for PISA Science 2006 (from OECD 2007)

- Understanding of the characteristic features of science as a form of human knowledge and inquiry
- Awareness of how technology shapes our material, intellectual, and cultural environments
- Willingness to engage in science-related issues with science as a reflective citizen (OECD 2000)

With this definition, PISA Science was firmly committed to what Roberts (2007) was to describe as a Vision II approach to science knowledge, that is, one that looks outward to science and technology (S&T) in the everyday real world rather than inward to the sciences as specialized disciplines (Vision I).

The scientific literacy definition was differentiated as three cognitive and three affective scientific competences – identifying scientific issues, explaining phenomena scientifically, and using scientific evidence and interest in science, support for science, and responsibility toward resources and environments. The more specifically described competences were then the guides for the design of test units consisting of an S&T context about which several items could be asked relating to these competences. A fuller description of this use of science contexts in assessment and some of its shortcomings are discussed in Bybee et al. (2009).

The Mode of Assessment

The use by PISA Science of a paper and pencil mode of assessment has both positive and negative outcomes for science education. This mode made the testings, in general, a familiar activity to many (but not all) of the countries' students. Since PISA Science was not bound by a curriculum sense of science, PISA could use fewer simple multiple-choice items and hence more of more valid types of item, complex multiple choice, and free response. The inclusion of the range of item types in the projects should encourage countries and their schools to also use a wider range of assessment items since the more precise and open ones can then offer diagnostic as well as formative indications of student learning.

The development of the achievement tests for PISA Science (and for TIMSS) has involved procedures to ensure validity and reliability that go beyond those used in most countries. They include extensive face validity of the items among panels of experts, linguistic and cultural analyses for bias, and statistical analysis of extensive trials with student samples in several countries to establish each item's discriminating power (for PISA see McCrae 2009). These thorough approaches to test development now stand as exemplary models for the development of similarly intended assessment instruments at a national, regional, or local level of education, where extra-school tests and even fewer of the intraschool tests set by science teachers have such good item design.

Difficulty Level of Items

Retrospectively, the very large number of responses to its items enabled six levels of difficulty to be identified. The cognitive demand in the items of any of these levels was then described leading to quite new understanding of this feature of science learning that provides an indication of these depth dimensions for science learning that can have diagnostic usefulness for teachers when teaching an associated topic (OECD 2007).

Assessment of Affect About Science

In the years since PISA began, there has been an accelerating stream of reports from international and national studies that indicate a decline in student interest in science and in science careers, particularly across the more developed countries. As in its approach to cognitive science learning, PISA Science broke new ground in associating interest in, support for science, and responsibility for the environment to the specifics of the science content and context as well as with a more generic measure of the first two. Thus, affective items were embedded in the contextual units as well as being asked in the student questionnaire.

The embedding of affective along with cognitive items in the main assessment test was a major innovation and contribution to science education in two ways. Firstly, it signaled very clearly that both types of learning were natural expectations from compulsory school science. Secondly, the embedding meant that students could respond positively to the specific science in one contextual unit and negatively to what underlay another contextual unit. A much richer portrayal of their affect resulted. This approach to affective responses to science is discussed in detail (see Olsen et al. 2011).

A negative aspect of PISA Science lay in its use of the paper and pencil mode, since there are now a number of commonly agreed curriculum goals for school science education that are not amenable to this mode of testing. The classic and abiding example of these is the assessment of practical performance in science, but now decision making about socio-scientific issues, context-based science, and science project work in and outside school can be added as not amenable to this mode of testing (see Fensham and Rennie 2013). The OECD's and PISA's silence on this point can be interpreted as suggesting they are not of worth.

Another unfortunate practice in these large-scale projects is that they release only a small fraction of the items from any one testing so that their elegance as scales is never publicly evident. By now however, enough items have been released for them to be used as reliable "item banks" for the types of science learning that PISA Science intends.

Cross-References

- ▶ Accommodation in Assessment
- ▶ Interests in Science
- ▶ Programme for International Student Assessment (PISA)
- ▶ Validity and Reliability of Science Assessments

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Assimilation

- ▶ Piagetian Theory

Attained Curriculum

► Curriculum

Attitude Differences and Gender

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Attitude Differences and Gender in Science Education

In US secondary and postsecondary schools, it is common to hear talented female students telling their peers that they are “not a [math/science] person,” even if their grades in these subjects suggest otherwise. Girls seem to develop this idea at a young age. Analyses of national data on US youth indicate that there are no notable gender differences in whether students “like science” in fourth grade, but differences emerge in eighth grade and grow stronger by 12th grade: 56 % of boys like science as compared with only 48 % of girls. This data shows that girls also have a greater tendency to report that they are not “good” at science (Bae et al. 2000, pp. 52–54). Fourth grade girls report being more likely to persist in science even if given a choice and less likely to consider science a “hard” subject, but this pattern is flipped by 12th grade, when 36 % of girls say they would not take more science (as compared to 30 % of boys) and 56 % say science is hard (as compared to 44 % of boys).

Studies suggest that gendered differences in attitudes toward science develop early, shaping female and male students’ pathways from early exposure to science through their choice of career. Parents and teachers play a role in shaping children’s gendered attitudes about science. When gender is salient in the classroom, preschool children appear to display preference for same-sex peers and exhibit behavior more closely in line with gender stereotypes (Hilliard and Liben 2010). When young people internalize the gendered messages they receive about certain career fields (e.g., science careers), they may steer away from areas in which they perceive that they are not expected to do well. Studies suggest that this pattern is heightened among the most mathematically and scientifically talented girls, representing a critical pool of potential “lost” scientific talent. These girls may consider their female identity to be mutually exclusive with a scientific identity. They may also be less likely to believe that they are indeed scientifically talented. Evidence suggests that girls develop lower assessments of their mathematical and scientific ability – irrespective of their observed ability – as compared to otherwise similar boys. These culturally influenced attitudes help to explain females’ higher rate of selection out of the pipeline to scientific careers. Biased attitudes about gender and science tend to be implicit, but nevertheless can shape behavior – including engagement and achievement (Nosek and Smyth 2011).

These biased attitudes have important effects on the available labor pool of scientists. Even though girls and boys who choose postsecondary specializations in the physical sciences, engineering, mathematics, and computer science have similar profiles, overall girls seem more likely to choose postsecondary majors in male-dominated fields like biology, clinical and health sciences, and the social and behavioral sciences, even when controlling for ability (Perez-Felkner et al. 2012). Males remain more likely to complete doctoral degrees in these scientific fields than females, across all racial-ethnic groups. The persistence of this trend is perhaps even more puzzling considering recent and mounting evidence that women are outpacing men in educational attainment, an emerging global phenomenon. Importantly, promising research shows that enrolling introductory physics undergraduates in short values-affirming writing assignments narrows the gender gap in course performance (Miyake et al. 2010). In conjunction with related research on the negative effects of salient gender stereotypes on female students’ performance on scientific tasks, these findings suggest that policy interventions aimed at affirming young women’s place in the sciences might mitigate the negative effects of persistent culturally influenced attitudes to the contrary.

Cross-References

- ▶ Achievement Differences and Gender
- ▶ Attitudes, Gender-Related
- ▶ Careers and Gender
- ▶ Gender
- ▶ Gender-Inclusive Practices
- ▶ Socio-Cultural Perspectives and Characteristics

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Attitudes to Science and to Learning Science

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Introduction

The study of school students' attitudes towards science and learning science has been a prominent feature of science education for 40–50 years. Concerns about declining attitudes have led to many studies of the possible influences on students' attitudes and of strategies that can be undertaken to improve attitudes.

The entry draws on five selected major review articles to demonstrate key findings from a range of studies and to explore the field for future reference. The first of these, by Osborne et al. (2003), sets out the main issues arising from an extensive review of the literature up to 2003. The authors explore what is meant by attitudes towards science, provide an overview of how attitudes have been measured, and discuss findings about the influences of gender and environment (including teaching) on attitudes and what is known about the relationship between attitudes and achievement. The second article by Barmby et al. (2008) provides additional analysis of and references to attitude studies, with specific commentary on a range of similar issues arising from their own research.

More recently, with reference to the Programme for International Student Assessment (PISA), where students' interest was a component of scientific literacy, the focus in reviews by Christidou (2011) and Krapp and Prenzel (2011) has shifted towards studies of students' interest in science. The relationship between attitudes and interest is explored from analyses presented in these two articles, together with further insights into the measurement of students' interest. Additional to this focus on interest, the work of Swarat et al. (2012) presents a more detailed investigation into students' interest in school science that could enhance our understanding of how school science can serve to influence students' attitudes.

Attitudes Towards Science: What Do We Mean?

Osborne et al. point out that there has been a lack of clarity of meaning with respect to attitudes. These authors draw on earlier work to make a distinction between attitudes towards science and scientific attitudes; the latter being "a complex mixture of the longing to know and understand, a questioning approach to all statements, a search for data and their meaning, a demand for verification, a respect for logic, a consideration of premises and a consideration of consequences. . .these are the features that might be said to characterize scientific thinking" (p. 1053). Attitudes towards science on the other hand are the "feelings, beliefs and values held about an object that might be the enterprise of science, school science, the impact of science on society or scientists themselves" (p. 1053).

Osborne et al. draw attention to the complexity of attitudes and the many constructs that can comprise attitudes. They also focus on the relationship between attitude, intention, and behavior, with reference to the theory of reasoned action developed by Ajzen and Fishbein in the 1970s, which is concerned with predicting behavior. As Osborne et al. report, this theory has been applied to a range of attitude and behavior studies in science education, some of which demonstrate how attitudes towards school science (as distinct from science in society) influence choice to study science. A further, more precise, definition of attitudes is used by Barmby et al. who recognize three components of attitudes as cognition, affect, and behavior – "a person has knowledge and beliefs about objects that give rise to feelings about them, and these two components together may lead a person to take certain actions" (p. 1078). This definition of attitude is similar to that of student engagement as used in many other studies of student affect in science.

The more recent focus on interest raises the question of what "interest" means in relation to "attitude." Whereas Osborne et al. refer to interest as a form of attitude, Krapp and Prenzel draw attention to a distinction between attitude and interest, suggesting that a difference arises with respect to the evaluation criteria that are the focus: "general, nonpersonal evaluation viewpoints are decisive for an attitude to a particular object, whereas the subjective value attached to the knowledge about this object is important for interest" (p. 31). Thus, one can have a negative attitude towards something yet be interested to know more about it. The focus on interest in science and school science has contributed to our understanding of how attitudes may be shaped by both personal and environmental characteristics. Krapp and Prenzel draw on previous work in making a distinction between individual interest and situational interest, the overall notion of "being interested" coming from both personal motivation and also the conditions of a learning situation (interestingness).

Measurement of Attitudes and Interest

Many instruments have been devised to measure attitudes towards school science, and both quantitative and qualitative methods have been used in attitude studies. Osborne et al. review subject preference studies that include the use of surveys that require students to rank subjects and also focus group studies that explore views in more depth. Most common, however, is the use of questionnaires that consist of Likert scale items where students are asked to agree/disagree with various statements such as "science is fun"; "I would enjoy being a scientist" (p. 1057). Most scales use a five-point range – strongly agree/agree/not sure/disagree/strongly disagree – and include a set of items designed to cover a range of constructs and which have been piloted to test for reliability. A number of examples are included in Osborne et al.'s review. These authors caution that scales that include items covering a range of different attitude constructs cannot lead to a single attitude score, as this would be meaningless. Examples of qualitative studies in Osborne et al.'s review point to their value in providing insights into the origins of attitudes to school science.

Barmby et al. measure clearly defined attitude constructs in their study using a questionnaire, and these include "learning science in school; practical work in science; science outside of school; importance of science; self-concept in science; future participation in science" (p. 1077). The reliability values and factor analyses confirmed that the three factors of learning science in school, science outside of school, and future participation in science could be brought together to provide a combined "interest in science" measure.

In their review, Krapp and Prenzel point out that more domain-specific interest measures are less frequently used. They discuss at length the issues pertaining to domain-specific interest measures and describe an example of a differentiated instrument used for a study in physics, which included three dimensions: topics, contexts, and activities – within which were eight topic categories, seven context areas, and four kinds of activity, in all, 88 items. Factor analysis could then determine the construct of “interest in physics.” This kind of breakdown of what the interest is about can enrich studies that look at specific subjects/domains of science and environmental factors. Krapp and Prenzel review other research approaches for studying interest, including observations, interviews, and databanks available on the Internet.

Attitudes in Relation to Various Factors

This section provides an overview of the findings reported in the five articles that focus on key issues relating to students’ attitudes towards and interest in science and school science. Where it exists, a distinction is made between findings that relate to science, as opposed to school science or learning science.

Age

Osborne et al. report on a range of studies that show a decline in attitudes towards science in early adolescence, in some cases even earlier. A more detailed analysis of studies does highlight a distinction between attitudes towards science and attitudes towards school science, as many 15-year-olds have positive attitudes towards science, finding it interesting, useful, and relevant, particularly in relation to technological advances, whereas school science is seen as rooted in past discoveries. Barmby et al. found a steep decline in attitudes towards learning science between students aged 11 and 13. Qualitative evidence showed that reasons for this decline in attitudes included lack of practical or lab work, weak explanations, and the perception that school science is not relevant. Krapp and Prenzel question the theoretical and practical relevance of how these trends are measured and judged, as they do not provide an insight into interest development in specific subgroups or subjects. These authors call for a more exact analysis of data from longitudinal studies. They report on one such study in physics that demonstrated that when physics is taught so that students can recognize a direct connection to practical life situations, then interest remains stable or increases.

Science Subject/Domain

Students’ attitudes to school science can vary according to subject (Osborne et al.); some findings indicate that biology is perceived as more relevant as it addresses students’ interests in their own bodies and health and disease, whereas the physical sciences are seen as less relevant, particularly chemistry, with topics such as the Periodic Table, the Haber process, and the Blast furnace being seen as least relevant. Osborne et al. also report on subject preference studies that show chemistry to be less appealing than physics. Many studies show gender differences in attitude towards different subjects and topics; Christidou reports that physics is the least attractive discipline for girls, who tend to be more attracted to studying animals and health or aesthetic topics. Swarat et al. report on research that shows the interest of younger students to focus on biology, technology, and astrophysics. Their research with students in the sixth and seventh grades shows that activities or topics based on technology or the human body are significant predictors of overall interest in science.

Gender

Research undertaken between 1970 and 1990 demonstrated that boys had more positive attitudes to school science than girls (Osborne et al.). Analysis of reasons indicated a range of possibilities from the early childhood experiences of boys playing with more scientific toys to perceptions of difficulty of the subject – girls believing themselves to be better at other subjects. Studies undertaken after 1990 provide evidence that girls believe themselves able to follow careers in science, even though they are less likely than boys to do so. However, gender influences are complex, as personal attributes such as self-concept and self-efficacy are operating with environmental effects such as single-sex schools or style of teaching. Krapp and Prenzel highlight the importance that such attributes play in explaining gender-specific differences in interest in science.

As Barmby et al. report, more recent studies have shown that the factor “who students want to be” has more prominence than previously and they conclude that attitudes are influenced by the current social contexts in which they are conducted. They also report that differences between boys’ and girls’ attitudes towards science outside school increase markedly with age, the difference being quite small at age 11 and more marked at age 13–14 years. Decline in attitudes to learning science in school occurs with both boys and girls but is still more pronounced with girls. With reference to international studies, Krapp and Prenzel report that differences between boys’ and girls’ interest in future careers in science are now only small. Moreover overall interest is more markedly different between less industrialized countries (where interest is higher for both males and females) and countries with advanced technological development.

Christidou focuses more specifically on students’ images of science and scientists that reveal gender stereotypes regarding professions perceived as scientific. Girls more than boys see science as “competitive, impersonal, abstract, rule-founded, certainty-bounded, deprived of imagination and as a product of individual effort made exclusively by male scientists” (p. 144). Though her review of studies also suggests that boys are more interested in science than girls, particularly in relation to some subjects (see above), she has found convergence in male and female interest in topics related to human biology, plants and animals, light and sound, and astronomy. Moreover, girls are more influenced by the interpersonal dimension – the presence of other people who they admire.

Environmental Factors

Though background factors such as parental influence and socioeconomic status can play a part in contributing to students’ attitudes towards science and school science, the most significant determinant of attitude is classroom environment (Osborne et al.) and in particular quality of science teaching: “Good teaching was characterized by teachers being enthusiastic about their subject, setting it in everyday contexts, and running well-ordered and stimulating science lesson. . .. talking with the students about science, careers and individual problems” (p. 1068). One important aspect of good teaching that these authors report is specialist knowledge, for example, low attitudes to science subjects could be attributed to teachers teaching outside their specialist subject with less enthusiasm.

Christidou also reports on the relationship between negative attitudes and the way science is taught. Teachers themselves need to have a positive stance towards science and scientists in order to inspire their students. The situation is not helped when school science is fragmented into isolated disciplines, and is limited in how it addresses values and social issues. Christidou’s review also looks at the popular images of science in relation to students’ interest and attitudes towards science. In focusing on the implications of how science is perceived by students, she reviews studies that have aimed to enhance students’ involvement in science through providing different learning environments. For example, she points out that involvement in a variety of informal out-of-school science activities may be associated with a firmer commitment to science and science learning. Swarat et al. focus on “activity type” in their study of students’ interest and show that inquiry-based teaching practices impact positively on motivation, interest, curiosity and enthusiasm. Their study on instructional episodes shows how different types of activity account for most variation in students’ interest, as opposed to content topic or learning goal.

Achievement

The nature of any relationship between attitude and achievement has been a key concern of many studies, but the evidence is inconclusive regarding this relationship (Osborne et al.). While some studies show a positive correlation, others show that students can achieve highly in a subject without having a positive attitude towards it.

Implications for Future Research

The authors of these selected articles call for an agenda for future research to establish a greater understanding of how pedagogic practice can enhance students' attitudes. In spite of the wealth of studies reported in these articles, research is still needed that looks at the way science is presented to students, including the values connected to science (Christidou). Developments in science pedagogy could be the focus of attitude research; studies that build on Swarat et al.'s work on activity could determine the kinds of classroom interventions that are appealing to students and influence students' interest in and attitudes towards science and learning science. Related to this issue is the education of future science teachers and research on the impact of such preservice education; teacher educators and school mentors could focus on raising the awareness of new teachers of what students find interesting, relevant, and inspiring to engage with science. Changes in the curriculum could also form part of an agenda for future research, including how the content of the curriculum (including its omissions) is relevant to students' developing values, interests, and attitudes.

Attitudes, once formed, may be relatively stable for individuals, but the shaping of attitudes is complex and also context dependent, which makes the task of determining attitudes in a changing world dynamic and never-ending. As Osborne et al. point out "attitude cannot be separated from its context and the underlying body of influences that determine its real significance" (p. 1055). Findings of studies conducted over different time periods relating to age, gender, and cultural background do vary as different contexts and influences operate. Ongoing research is needed to capture changing trends in the relationship of age, gender, and culture to attitudes towards science.

Attitude studies that have included mixed methods have provided quantifiable data that is supported by more in-depth analyses that deepen our understanding of how attitudes towards science are influenced. The development and use of inventories that measure motivation and personal attributes of students can be coupled with studies of pedagogy and learning environments to determine relationships between variables. Longitudinal studies that take into account a host of such variables can be used to inform policy and pedagogy – how to resource and support science and communication about science and to fund the pre- and in-service education of science teaching.

Though we already have a rich resource of research in this field, these five articles provide some ideas for possible future research on attitudes towards science that would have considerable benefit for science education.

Cross-References

- ▶ Affect in Learning Science
- ▶ Attitudes Toward Science, Assessment of
- ▶ Competence in Science
- ▶ Interests in Science

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Attitudes Toward Science, Assessment of

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Students' Attitudes and their Measurement

Most children come to school ready and willing to learn. International surveys of primary age children generally reveal high levels of interest and positive attitudes of children to subjects such as science. Unfortunately, as children move through the education systems, their positive attitudes toward science typically decline, and increasingly fewer students are interested in studying science and to work in science-related careers.

Science and technology have enabled remarkable achievements, and their role in society continues to grow as the world faces the new challenge brought about by globalization and the serious test of how to protect the environment while promoting economic growth and sustaining an increasing world population. In order to successfully address these challenges, countries will have to make major investments in scientific infrastructure and the ability to attract, retain, and reward qualified individuals into science-related professions. Countries will also have to secure broad public support for scientific endeavor and ensure that all citizens are able to make use and benefit from science in their lives.

People's attitudes toward science are an integral part of whether they can be considered scientifically literate or not, as they determine whether individuals are willing to engage with science: attitudes and motivation in fact play a significant role in how interested people are in science and technology, how much attention they devote to scientific issues and technological progress, and how they respond to scientific challenges. The Programme for International Student Assessment (PISA) has examined how well 15-year-olds worldwide perform in science since 2000 and in 2006 closely examined what attitudes students have toward science and how motivated they are to study science and to work in science-related careers. In 2015 PISA will monitor closely student attitudes toward science for a second time and by so doing will be able to illustrate trends in what students think about science and their views on why studying science matters for them and society more widely.

Students participating in the PISA 2006 study sat for a 2-h test aimed at assessing their level of proficiency in science, mathematics, and reading. After completing some specific test questions related to science, students were asked to report their support for a number of statements directly linked to the science topics they had just encountered. After the test, students also completed a questionnaire where they were asked questions about themselves, their household situation and also whether they agreed or not to a series of statements developed to assess their attitudes toward science. Students' responses to the assessment-embedded questions and to the background questionnaire were used to develop measures identifying several aspects of student attitudes toward science: what motivates students to learn science and how motivated they are, to what extent students value and enjoy science, whether students believe in their own science abilities, whether they believe they can perform specific scientific tasks, and whether students expect to work in science-related occupations. The sections below describe how PISA measured attitudes toward science in 2006 and illustrate gender and socioeconomic disparities in students' attitudes toward science.

Motivation to learn science. PISA distinguishes two forms of motivation to learn science: students may want to learn science because they enjoy it and find it interesting, intrinsic motivation to learn science, but they may also wish to learn science and excel in science because they perceive learning science as useful, extrinsic motivation.

Intrinsic motivation refers to performing an activity purely for the joy gained from the activity itself: students are intrinsically motivated to learn science when they want to learn science because they find science interesting and enjoyable and when they want to study science for the pleasure it gives them, not because of what they will be able to achieve upon mastering science subjects. Intrinsic motivation affects how engaged students are, the learning activities students enroll in, student performance in science, and the types of careers students aspire to have and choose to follow. Generally, intrinsic motivation declines from elementary school to higher education, but can be importantly shaped by what teachers do, by students' peers, by classroom instruction and dynamics, as well as by parental motivational practices, attitudes, and behaviors. PISA indicates that, within countries, students who have high levels of intrinsic motivation to learn science are highly proficient in science, although countries where students have, on average, comparatively high levels of intrinsic motivation to learn science are not necessarily the countries with the strongest science performance in the PISA assessment.

PISA 2006 provides three measures of students' intrinsic motivation to learn science: general interest in science, enjoyment of science, and interest in learning science topics. The first two measures were computed using students' answers to the student questionnaire. Students were asked how interested they were in learning about the following science topics: physics, chemistry, biology of plants, human biology, astronomy, geology, the ways scientists design experiments, and what is required for scientific explanations. The *index of general interest in science* combines students' answers on whether they have "high," "medium," "low," and "no" interest to learn these topics. *Enjoyment of science* was assessed asking students to answer whether they "strongly agreed," "agreed," "disagreed," and "strongly disagreed" that they enjoyed five different aspects related to science and learning science. The *index of interest in learning science topics* on the other hand was assessed using embedded questions in the assessment of students' performance after students had worked on cognitive items so that object-specific interest could be evaluated. The students were asked to indicate their interest in the topics, objects, and activities that they had just encountered.

Extrinsic motivation to learn science refers to the motivation that drives students to learn science because they perceive it as useful to them and to their future studies and careers. Extrinsic motivation was measured in PISA 2006 by assessing students' instrumental motivation to learn science and by assessing students' future-oriented motivation to learn science. *Instrumental motivation* to learn science was measured asking students to report whether they "strongly agreed," "agreed," "disagreed," or "strongly disagreed" to five statements aimed at capturing the importance students attach to learning science because it is useful, because it will help students succeed in their future jobs, or because it will help improve career prospects. Instrumental motivation to learn science is an important predictor of course selection and career choices, and results from PISA 2006 indicate that students perceive science to be useful and that they believe science can help them in their search for jobs and can help them pursue better career prospects (OECD 2007). Although instrumental motivation to learn science was highly correlated with science performance in some countries, in others the relationship was weaker or negative, with few differences between boys and girls. *Future-oriented motivation to learn science* was assessed by asking students to report whether they "strongly agreed," "agreed," "disagreed," or "strongly disagreed" that they would like to have a science-related career, to continue studying science after completing secondary school, and to continue to use science in their future lives. Future-oriented motivation to learn science was positively associated with science performance in 42 PISA participating countries and economies, including all OECD countries except Mexico, and the strength of the association is quantitatively important in as many as 20 PISA 2006 countries and economies.

Support for science. In 2006 PISA explored the extent to which students appreciate science and scientific inquiry and whether they believe science plays an important role in their own lives by asking students questions about how much they support and value science. Responses provided in the context of the student background questionnaire were used to develop a measure of students' general value of science and a measure of students' personal value of science. Responses that the students provided to questions that were embedded in the science assessment, after students had encountered specific test questions, were used to capture how students value science in relation to specific topics. Personal values of science are fundamental antecedents of emotional feelings about science such as enjoyment, motivation for learning science, and motivation for a long-term engagement in science. When students value science in their own lives, they are more likely to enjoy science and to be interested in scientific topics. Both general and personal values of science are related to students support for scientific inquiry.

A general value of science indicates to what extent students value the contribution of science and technology. The majority of students participating in PISA 2006 reported that they value science, and while almost all students participating in PISA reported that they believe science is important to understand the natural world and that scientific and technological advances usually improve people's conditions, significant proportions of students did not agree that advances in science and technology usually bring about social or economic benefits. While the overwhelming majority of students reported valuing science in general, far fewer students feel that science directly related to their own lives and behavior: students across all participating countries and economies had lower levels of *personal value of science* than general value of science. Scientific inquiry refers to valuing scientific ways of gathering evidence, the importance of considering alternative ideas, the use of facts and rational explanations, and communicating with others. On average, only 59 % of students reported that they would use science when they left school, 64 % of students reported that they would use science as adults, and only 57 % of students agreed that science was very relevant to them. When participating students were asked about their support for scientific inquiry immediately after they had solved specific science tasks in the PISA science assessment, students reported strong levels of *support for scientific inquiry*, for example, students supported research to develop vaccines for new strains of influenza and they valued the systematic study of fossils and that scientific research should be at the basis of statements about the causes of acid rain.

Personal beliefs. In 2006 PISA also assessed students' self-beliefs as science learners. Students with positive self-beliefs believe in their own ability to handle scientific tasks effectively and to overcome difficulties and in their own academic ability. Autonomous learning requires both a critical and a realistic judgment of the difficulty of a task as well as the ability to invest enough energy to accomplish it. Students' views about their own competences have been shown to have considerable impact on the way they set goals, the learning strategies they use, and their performance.

Self-efficacy goes beyond how good students think they are in subjects such as science. It is more concerned with the kind of confidence that is needed for them to successfully master specific learning tasks and therefore not simply a reflection of a student's abilities and performance. The relationship between students' self-efficacy and student performance may well be reciprocal, with students with higher academic ability being more confident and higher levels of confidence, in turn, improving students' academic ability. A strong sense of self-efficacy can affect students' willingness to take on challenging tasks and to make an effort and persist in tackling them: it can thus have a key impact on motivation. To assess self-efficacy in PISA 2006, students were asked to rate the ease with which they believe they could perform eight listed scientific tasks. For each of the eight scientific tasks, the average percentages of students reporting that they could do it either easily or with a bit of effort vary considerably. Seventy-six percent of students on average reported that they felt confident explaining why earthquakes occur more frequently in some areas than in others. Similarly, 73 % of students reported that they could recognize an underlying science question in a newspaper report on a health issue. Around 60 % of students on average reported that they could interpret the scientific information provided on the labeling of food items, predict how changes to an environment will affect the survival of certain species, and identify the science question associated with the disposal of garbage. Less than 60 % of students reported that they could describe the role of antibiotics in the treatment of disease or identify the better of two explanations for the formation of acid rain. Students were least confident with discussing how new evidence could lead to a change of understanding about the possibility of life on Mars, with only around half of 15-year-olds in OECD countries reporting that they could do so easily or with a bit of effort.

Students' *academic self-concept* is both an important outcome of education and a trait that correlates strongly with student success. Belief in one's own abilities is highly relevant to successful learning. It can also affect other factors such as well-being and personality development, factors that are especially important for students from less advantaged backgrounds. In contrast to self-efficacy in science, which asks students about their level of confidence in tackling specific scientific tasks, self-concept measures the general level of belief that students have in their academic abilities. To what extent do the 15-year-old students assessed by PISA believe in their own science competencies? On average, 65 % of students reported that they could usually give good answers in science tests. Overall, however, a large proportion of students (between 41 % and 45 % on average) said they were not confident in learning science, reporting that they did not agree that they learned school science topics quickly or understood concepts or new ideas very well. Furthermore, 47 % agreed that school science topics were easy and that learning advanced science would be easy.

Within countries, student attitudes toward science are associated with higher performance in the PISA science assessment in virtually all OECD countries; however, countries that have, on average, positive attitudes toward science are not necessarily countries with high mean science performance. For example, PISA, as well as other international studies such as TIMMS and ROSE, suggests that students in low-performing countries have relatively high levels of interest in science, while students in high-performing countries show relatively low levels of interest in science. Within countries internal motivation to learn science and instrumental motivation to learn science, participation in science-related activities, self-efficacy, and science self-concept are all strongly associated with science performance, with self-efficacy having the strongest association. Results from PISA 2006 suggest that, across OECD countries, students who have values on the index of student self-efficacy that are one standard deviation above the OECD mean score 28 points higher on average than students with average levels of self-efficacy. The score point differences associated with one standard deviation rises in the index of general interest in science and in the index of student self-concept in science are also close to 20 points. The differences are lower in relation to both the index of student participation in science-related activities and the index of instrumental motivation to learn science (16 and 14 points, respectively).

Gender differences. PISA indicates that 15-year-old boys and girls generally perform at similar levels in science, but boys and girls do not hold similar attitudes. For example, boys tend to have greater self-concept and greater self-efficacy in science than girls, as well as higher levels of enjoyment of science and instrumental motivation to learn science, but boys and girls have similar levels of intrinsic motivation to learn science. Recent meta-analyses show that boys have consistently more positive attitudes toward science than girls, especially toward physical science and engineering. Girls, on the other hand, tend to be more interested in health and life sciences. In 2006, PISA asked 15-year-old students what they expect to be doing in early adulthood, around the age of 30. In general boys and girls reported expecting to pursue careers in very different fields. In recent years, girls in many countries have caught up with or even surpassed boys in science proficiency. Better performance in science or mathematics among girls, however, does not mean that girls want to pursue all types of science-related careers. In fact, careers in "engineering and computing" still attract relatively few girls. Results from PISA 2006 suggest that among OECD countries, on average, fewer than 5 % of girls, but 18 % of boys, expected to be working in engineering and computing as young adults. In no OECD country did the number of girls who expected a career in computing and engineering exceed the number of boys contemplating such a career. Moreover, the ratio of boys to girls who wanted to pursue a career in engineering or computing is large in most OECD countries: on average, there were almost four times as many boys as girls who expected to be employed in these fields.

Even among the highest-achieving students, career expectations differed between boys and girls; in fact, their expectations mirrored those of their lower-achieving peers. For example, few top-performing girls expected to enter engineering and computing. Although few girls expected to enter some science careers, such as engineering and computing, in every OECD country more girls than boys reported that they wanted to pursue a career in health services, a science profession with a caring component. This pattern holds even after nurses and midwives are excluded from the list of health-related careers. On average across OECD countries, 16 % of girls expected a career in health services, excluding nursing and midwifery, compared to only 7 % of boys. This suggests that although girls who are high achievers in science may not expect to become engineers or computer scientists, they direct their higher ambitions toward achieving the top places in other science-related professions, such as those in the health field.

Differences by socioeconomic background. PISA reveals that socioeconomically advantaged students tend to have more positive attitudes toward science, as well as higher science performance, than their less advantaged peers. Given the strong association that exists between science performance and attitudes toward science, could the socioeconomic gap in science performance be closed if socioeconomically disadvantaged students had more positive attitudes toward science? What role do attitudes toward science play in helping disadvantaged students overcome the adverse circumstances determined by their socioeconomic background?

Results from PISA 2006 (OECD 2011) indicate that socioeconomically disadvantaged students tend to have less positive attitudes toward science than socioeconomically advantaged students. They also tend to engage less in science activities, feel less prepared for science careers, attend fewer science courses, and spend less time in science lessons at school. For example, disadvantaged students report being less interested in science and having lower levels of self-efficacy than their more advantaged peers in every OECD country and in most partner countries and economies. The differences in the extent to which disadvantaged students and their more advantaged peers report having low levels of instrumental motivation to learn science, participation in science-related activities, self-concept, and information on science-related careers are also significant in most OECD and partner countries and economies.

PISA 2006 further reveals that both disadvantaged students and their more advantaged peers benefit from having positive attitudes toward science. With a few exceptions, disadvantaged students benefit, on average, as much as their more advantaged peers from having positive motivation, participation in science-related activities, confidence, and perspectives future careers in science. There are, however, some important differences across areas. For example, in several countries, the association between attendance at compulsory science courses and performance is stronger for disadvantaged students than for their more advantaged peers. In addition, in a number of countries disadvantaged students appear to benefit less than their more advantaged peers.

These results suggest that positive attitudes toward science are associated with increases in the PISA score across all socioeconomic groups but crucially that the increases are smaller for disadvantaged students in some countries. Policies aimed at promoting greater motivation to learn science and positive attitudes and approaches to science learning may therefore result in absolute improvements in science achievement but may also run the risk of contributing to wider performance gaps across social groups unless they are targeted at specific populations.

Cross-References

- ▶ Action and Science Learning
- ▶ Assessment: PISA Science
- ▶ Attitudes to Science and to Learning Science
- ▶ Programme for International Student Assessment (PISA)

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Attitudes, Gender-Related

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Keywords

Gender; Science education

Gender is defined in various ways, but for the purposes of the encyclopedia entry on gender-related attitudes, gender is considered a social construct, not a biological one; that is, gender is not determined by one’s DNA and hormones, but rather by the accumulation of one’s sociocultural experiences.

Gender-related attitudes are initially developed and formed in a child’s home, affected by the actions and attitudes of teachers and friends, and reinforced by experiences in the workplace – or in society in general. Self-confidence in studying science, attribution of success in science, fear of failure in science, participation rates in science, perceptions of the usefulness of science, and performances in science all contribute to one’s gender-related attitudes about science. Further, gender-related attitudes contribute to a student’s aspirations and interest in science and are heavily influenced by teacher beliefs, expectations, and classroom behaviors.

Gender-related attitudes in science education have been studied extensively since the early 1980s. During that time, girls, compared with boys, have consistently reported more negative attitudes towards science in local, regional, national, and international studies. Although gender-related differences decline as students proceed through school and the decline is greater for girls than for boys, girls’ interest in science does not increase over time (Scantlebury 2012).

Cross-References

- ▶ Attitude Differences and Gender
- ▶ Attitudes to Science and to Learning Science

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Ausubelian Theory of Learning

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David Ausubel: An Introduction

David Ausubel was born in 1918 and graduated from the University of Pennsylvania with honors in psychology in 1939. In spite of his outstanding undergraduate record, Ausubel suffered from the prevailing medical school prejudice against Jewish students and could not get admitted to any of the best medical schools. Instead, he studied Experimental Psychology at Columbia

University and earned an MA degree in 1940. He completed the MD degree at Middlesex University in 1943 and then did three psychiatric residences with the US Public Health Service in Kentucky, the Buffalo Psychiatric Center, and Bronx Psychiatric Center. After military service in Germany, where he worked in the United Nations Relief and Rehabilitation Administration, Ausubel earned a PhD degree in Experimental Psychology at Columbia University in 1950. It was at Columbia that he first began to formulate his ideas that evolved into his *assimilation theory* of learning first published as a paper in 1962 and then as his 1963 book, *The Psychology of Meaningful Verbal Learning*. In 1968 he published a more comprehensive book, *Educational Psychology: A Cognitive View*. This book extended his theoretical ideas and applied them to other areas of educational psychology. In this work Ausubel offered educators an alternative theory of learning to the behavioral psychology that was almost universally embraced by psychologists in the 1960s. It was his theory of learning I adopted and adapted to my research and instructional design programs from 1963, first at Purdue University and then at Cornell University.

When I was a graduate student in Education at University of Minnesota, I took a graduate course in Theories of Learning. The text was Hilgard's 1948 book, *Theories of Learning*, and it presented only behaviorists' theories of learning. I recall complaining to the professor teaching the class that there was nothing in these theories that was useful to classroom teaching. While he did not deny my claim, he argued that Hilgard's book was the only one of its kind and was almost universally used in universities. I recall that my colleague at Cornell, Bob Gowin, had a similar reaction to a similar course at Stanford University where he did his graduate studies at about the same time. After the information processing/cognitive psychology revolution of the 1980s, it is hard for present-day scholars to appreciate what a profound departure from the prevailing educational psychology Ausubel was promoting with his new theory.

In 1965, I attended a conference on Concept Learning at the University of Wisconsin, and here I had a chance to have extended conversations with Ausubel about his theory.

These conversations helped me gain insights into his theory and its application to education. These conversations began a continuing dialogue with Ausubel, and in 1977, he invited me to assist in the revision of his 1968 *Educational Psychology: A Cognitive View*. During the course of these revisions, where I revised the key chapters dealing with his assimilation theory, I got deeper insights into his thinking. I was also amazed at his prodigious knowledge of the literature. On several occasions I recall calling Ausubel to discuss his interpretation of some research studies that did not seem evident to me. On all of these occasions, he would describe his thinking in reaching the conclusions he did from these studies. Considering there are over 1,400 research references in his 1968 book, I marveled at his ability to discuss specific studies over the phone. Ausubel had a remarkable intellect, a genius in his own way! I marveled at how he could sift through the dustbins of behavioral psychology and tease out research findings that could be used to contribute to his assimilation theory.

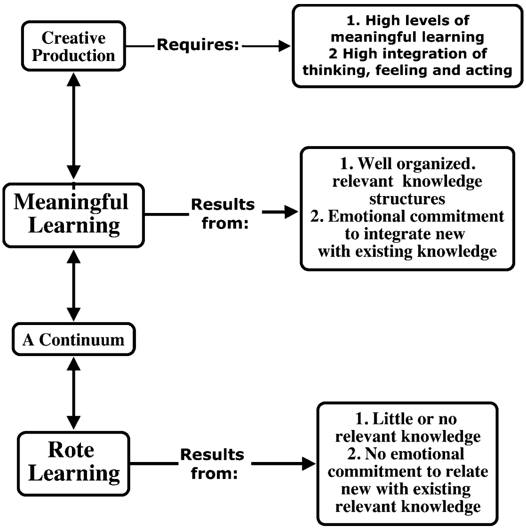
The Core of Ausubel's Theory

In the epigraph in his 1968 book, Ausubel wrote:

> If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.

Now this may appear to be simple enough, or even to some simplistic. However, it is not easy to ascertain carefully what the learner already knows on a given topic, and it is even more difficult to determine how best to teach him/her effectively. Indeed many of the major research programs focused on the learning and teaching of science that have been conducted over the last 30–40 years, including mine, have at their core been concerned in some form with one or both of understanding ways to determine "what the learner already knows" and then what it would mean to teach the leaner "accordingly."

When Ausubel speaks about what a learner already knows, he is speaking about the concepts and propositions that have meaning for this learner. In our work we have slightly modified Ausubel's definition of these terms to better fit current epistemological thinking. We define a *concept* as a perceived pattern or regularity in events or objects, or records of events or objects, designated by a label, such as a word or symbol. *Propositions* are two or more concepts linked to make a meaningful statement about events or objects. Propositions can also be thought of as the fundamental units of meaning, for concepts standing alone convey little meaning. Getting smart about a domain of knowledge requires building a powerful cognitive framework of concept and propositions for that domain, together with supportive feelings and skills necessary to achieve this organized body of knowledge.



Ausubelian Theory of Learning, Fig. 1 The rote-meaningful learning continuum (Novak 2010)

The Essential Principles of Ausubel's Theory

Ausubel's theory has six basic principles: *The first two principles* are ***rote learning***, which occurs when the learner makes little or no effort to relate new knowledge to relevant elements of knowledge the learner already knows, whereas ***meaningful leaning*** occurs when the learner makes a deliberate, conscious effort to relate new concepts and propositions to existing, relevant concepts and propositions. Only the learner can choose to learn *meaningfully*, although there are strategies that can encourage this kind of learning. In the 1970s Ausubel argued that rote learning and meaningful learning are two different, distinct ways of learning. I argued that it was my experience at that time indicated that the quality and extent of meaningful learning depended both on how much effort and commitment the learner makes to relate new learning to her/his existing knowledge and also on the quality and degree of organization of that existing relevant knowledge. Therefore, cognitive learning should be viewed as a continuum, varying from very rote, arbitrary acquisition in information to very high levels of meaningful learning. More recently I have argued that creativity could be viewed as essentially very high levels of meaningful learning. This view is expressed in Fig. 1.

While Ausubel accepted the idea that rote and meaningful learning can be viewed as a continuum, he always held that creativity was a special capacity possessed by relatively few very gifted people. To be sure, only a very small fraction of the population have the capacity to organize their thinking, feeling, and acting in ways that lead to the extraordinary creativity of an Einstein or a Mozart. However, most normal individuals can on occasion gain novel insights in a limited sphere knowledge creation. This view is discussed later in this entry.

The third key principle of Ausubel's theory is ***subsumption***. When new concepts and propositions are incorporated into relevant, more general concepts and propositions, ***subsumption*** occurs and both the existing superordinate knowledge and the newly incorporated idea are modified. Ausubel maintained that subsumption is the most common form of meaningful learning. This view has been supported by our research and the research of others. In extreme rote learning, the process of subsumption does not occur where one can think of the new bits of knowledge as just kind of floating around in cognitive space, each in isolation of all other elements. There are two negative results from this kind of rote learning. First, there is no enhancement and refining of meanings for existing concepts and propositions. Consequently these existing ideas do not (and cannot) become more powerful subsuming concepts nor more differentiated ideas that can serve better for problem solving or creative work. Second, faulty ideas or ***misconceptions*** held by the learner do not get "corrected" or altered into more accurate forms. Research has shown that students who learn primarily by rote are poor at solving novel problems and they do not modify and correct their faulty conceptions; nor do they consider in any way relevant alterative conceptions they use to interpret their world.

The fourth principle in Ausubel's theory is ***obliterative subsumption***. This occurs when over a span of time, discrete ideas are subsumed into more general concepts and later can no longer be recalled as discrete ideas (hence "obliterative"). These concepts and propositions have contributed to elaborating the more general idea into which they were subsumed, but we can no longer recall them independently. All of us have experienced occasions when we knew that object or event belongs to a certain category of things or events, but we cannot recall the details of that object or event. Obliterative subsumption that occurs after some meaningful learning event is not the same as forgetting that occurs after rote learning. There remain some enriched concepts and propositions in your cognitive structure and these will *facilitate* new, relevant learning. When forgetting occurs after rote learning, there is usually *interference* or retarded learning of related material. No doubt the reader can recall being confused in trying to recall something recently learned because of the new ideas are still jumbled up with similar things in our minds and we cannot sort out the details. For many of us, including me, a good example of this is trying to recall names. Unless I have made some kind of meaningful connection to a person's name and something related to that name, I might forget the name in a minute or two!

The fifth principle in Ausubel's theory is ***superordinate learning***. This kind of learning occurs when several concepts or propositions are recognized as really subordinate units of some larger, more inclusive idea. For example, children learn that there are pigs, cows, dogs, and similar animals. When they acquire the superordinate concept of mammal, i.e., something with hair or fur and females with mammaries to nurse their young, superordinate learning has occurred. Similarly, one may learn about many events that occurred in France and Europe in the fourteenth to seventeenth centuries. This lays the foundation for coming to understand the period as the ***renaissance*** and this adds a superordinate concept to enrich the meanings of the individual events you have studied.

Finally (the sixth principle), there is Ausubel's principle of ***integrative reconciliation***. An example of this principle at work is when a child realizes that multiplication is really just a form of repeated addition. The child now sees that $2 \times 3 = 6$ is the same as $2 + 2 + 2 = 6$. So much of mathematics would be more easily learned and remembered if teaching was designed for encouraging repeated integrative reconciliation of component ideas. Of course, this is also true in every other discipline.

A general comment about these six principles: Many people have found it difficult to grasp Ausubel's assimilation theory of learning. In part, and in common with the totality of any complex theory in any discipline, this is because each of the principles in this theory is related to all the other principles. One cannot really understand integrative reconciliation until one understands meaningful learning and superordinate learning. One cannot grasp the meaning of all six principles in a single sitting or session. One must get a beginning understanding of each and gradually refine and build those meaning over time with numerous examples and experiences. Profoundly important ideas are profoundly difficult to master. My counsel is to just begin to work with these ideas and they will become more clear and powerful over days, weeks, and months.

Advance Organizers

Ausubel also advanced the idea of advance organizers, and at times in the past, it seemed he was better known for this than for his theory of learning. His, and others', research shows that if one precedes a segment of instruction with a more general, more abstract segment of instruction on a topic to be studied (an "advance organizer"), this can help the learner integrate the new details to be learned with existing relevant subsumers, thus facilitating meaningful learning. The advance organizer serves as a kind of "cognitive bridge" helping the learner to recognize existing relevant concepts and propositions she/he possesses and facilitating subsumption of the new information.

The idea of advance organizers is not part of his theory of learning but rather an instructional strategy. Other psychologists have advanced similar ideas usually termed ***scaffolding*** (Hogan et al. 1997) learning. In either case, the goal is to help the learner assimilate new more explicit material to be learned into her/his cognitive structure. When an advance organizer is well planned, it should help the learner see relationships between some more general, relevant idea they already know and the more specific, more detailed concepts and propositions to be learned. In other words, a good advance organizer facilitates the subsumption of new relevant concepts and propositions.

Many studies have shown that the use of advance organizers significantly enhances meaningful learning of more detailed, relevant information, including two studies done by one of my graduate students. Kuhn found that biology laboratory students who were given an advance organizer to study prior to instruction on homeostasis and levels of biological organization did significantly better when tested on these ideas at the end of the laboratory and 3 weeks later, when compared with students not given these advance organizers. Some research studies have failed to show a positive effect for "advance organizers," but in most of these cases, either there were inappropriate advance organizers or the achievement tests used did not require significant meaningful learning. Testing only for recall of specific details is not likely to show the advantage of using an advance organizer, because there is no logical reason to suggest that an advance organizer could do anything to assist rote learning.

Primary and Secondary Concepts

Ausubel distinguishes between primary concepts and secondary concepts. *Primary concepts* are those acquired from direct experience with objects or events, and these can be acquired readily by the young child. *Secondary concepts* are derived from perceived regularities in relationships between primary concepts, and these are more difficult to acquire. Energy is an example of a secondary concept, and acquisition of this concept requires direct experiences with objects or events that manifest the concept and guidance in observing the manifestations of the regularity that defines the concept. A young child can learn about atoms and molecules and energy and energy transformations providing they are given experiences where these concepts are manifest and they are given guidance to observe the patterns or regularities that manifest the concept. Thus, children can be provided with experiences and guidance to understand the particulate nature of matter and the effect of adding heat to a sample of matter, such as heating a balloon. In a 12-year longitudinal study, we showed that 6–8-year-old children when provided with appropriate experiences and audio guidance in their observations can begin to acquire functional concepts of matter and energy and energy transformations (Novak and Musonda 1991). Moreover, as these children progressed through the grades, those who had this early instruction demonstrated twice as many valid concepts about the nature of matter and energy and less than half as many misconceptions, compared with similar students who did not have this early instruction.

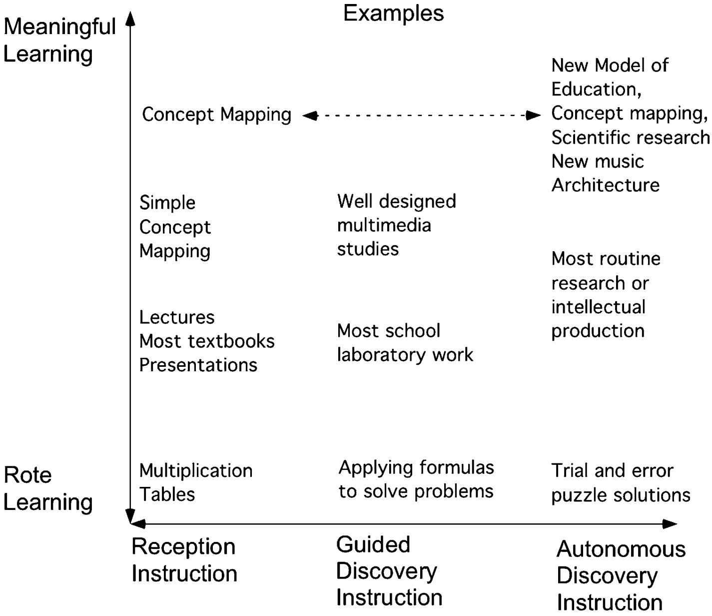
Reflections on Ausubel's Theory of Learning

Ausubel held a more conservative view about the learning capabilities of young children than many of the researchers who subsequently worked with his theory. I think this is due to the fact that he did very little research with young children, whereas the work of others (including my research programs) has involved this age group. In the last 20 years, there have been numerous studies by a range of researchers (from cognitive scientists to early childhood educators with expertise in science) that show we have consistently and grossly underestimated the learning capabilities of young children.

Many researchers, including many graduate students, embraced Ausubel's theory as a powerful and useful theory to guide their research on learning science. However, most of my colleagues in Science Education in the USA rejected his ideas or simply ignored them. The work of Piaget, interpreted as if he was a developmental psychologist, began in the mid-1960s to dominate thinking in Science Education in the USA and to a lesser extent in the UK and some other countries. The ways in which researchers interpreted Piaget held that children's intellectual development progressed in stages that were highly age determined and could not be accelerated. The unfortunate result of this doctrinaire interpretation of Piaget's writing in the USA, and in particular the less complex parts that related to views about stages of intellectual development, was that the teaching in the country of basic concepts of science such as the nature of matter and energy was delayed until around Grade 8 at the earliest. The consequence was that powerful superordinate concepts dealing with the nature of matter and energy were not introduced in elementary school and much learning facilitation that could have resulted from such teaching was lost.

It might be argued that no harm is done by delaying instruction in basic science concepts if it were not for the highly documented fact that children build their own *alternative* science concepts based on everyday experiences. While consistent with the child's interpretations of their experiences, the majority of these alternative concepts are completely inconsistent with science, and so are faulty concepts or misconceptions. For example, children think that one must keep applying a force to an object to keep it moving at a steady speed, whereas the much more powerful science explanation of this phenomenon is that for this motion the resultant force on the object is zero (and so no continuing force is needed if we remove the friction of air and the surface traveled). Children believe that plants get their food from the ground, since they observe people applying "plant food" to lawns and gardens. Without a basic understanding of atoms and molecules and energy and energy transformations, they cannot understand how plants synthesize their own food from carbon dioxide in the air and nutrients absorbed by the roots and transported to the leaves. Once these faulty alternative conceptions are acquired, thousands of studies have shown it is notoriously difficult to help students learn valid science concepts. Perhaps the central reason for this is that the faulty concepts seen by the child as relevant still function as Ausubelian subsumers to anchor learning of new relevant concepts and propositions, often further elaborating and distorting the alternative conception. Even conscientious efforts on the part of the teacher and the students to learn new material meaningfully can fail due to the student's faulty alternative conceptions (see Proceedings of International Conferences on Science and Mathematics Misconceptions held at Cornell University at: www.mlrg.org).

An early exploration of the value of Ausubel's theory for guiding and interpreting research and instruction in science was undertaken in 1971, when two of my graduate students and I reviewed over 100 published research studies in science education with the view of looking at these studies through the lens of Ausubel's theory of learning (Novak et al. 1971). We found most of the studies sorely lacking in theoretical foundations, many using inappropriate data analysis, or lacking adequate control of variables and



Ausubelian Theory of Learning, Fig. 2 High levels of meaningful learning can be achieved by both reception learning approaches and discovery approaches, and both approaches can result in little meaningful learning when poorly done (Novak 2010)

frequent use of inadequate assessment tools. More relevant here is that we found that Ausubel's theory would better explain the data obtained and could have guided better instructional and research design. One of the most powerful tools invented to establish what a learner knows, to represent expert knowledge, and to facilitate learning of new knowledge is the *concept map*. This tool was developed in Novak's research program at Cornell University in the early 1970s and is now used in all disciplines for all ages all over the world. Further discussion of this tool can be found in in the entries ▶ Concept Mapping and ▶ Concept Maps: An Ausubelian Perspective. Ausubel's learning theory was the primary theoretical foundation for the development of this tool.

For many years the science education literature, both research and professional, and wider public debate about science teaching and learning have been replete with recommendations for greater emphasis on *inquiry* approaches to teaching and learning. Sometimes, indeed too often, these recommendations derive from simplistic views of "discovery," "child centered," and other slogans. More substantively, many of these recommendations derive from the mistaken view that *reception learning*, where the learner is guided to acquire new knowledge primarily through didactic teaching, is basically inferior to "discovery" or "inquiry" approaches to learning. Ausubel points out that while poor reception teaching leads primarily to rote learning, with all the inherent shortcomings, when well done, reception learning can not only be highly efficient but also provide many of the benefits and future utility of knowledge acquired when reception instruction is well done. This is not to say that discovery or inquiry learning should have no role in school learning, as there are ancillary benefits that are valuable, such as learning to design experiments and gaining skills in using scientific equipment. As shown in Fig. 2, well-designed reception instruction can lead to highly meaningful learning, and poorly designed inquiry instruction can result in little or poor learning for understanding.

Today almost all educational psychologists subscribe to some form of cognitive or socio-cognitive learning theory. The pioneering work of Ausubel is of central relevance to cognitive considerations. It still merits careful study and remains a viable and powerful theory of human learning.

Cross-References

- ▶ Alternative Conceptions and P-Prims
- ▶ Alternative Conceptions/Frameworks/ Misconceptions
- ▶ Cognitive Acceleration
- ▶ Concept Maps: An Ausubelian Perspective
- ▶ Conceptual Change in Learning
- ▶ Developmental Perspectives on Learning
- ▶ Imagination and Learning Science
- ▶ Information Processing and the Learning of Science
- ▶ Metacognition and Science Learning
- ▶ Metaphors for Learning
- ▶ Piagetian Theory

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Authentic Assessment

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Keywords

Alternative assessment; Computer simulation; Direct assessment; Field experience; Group discussion; Open-ended problem; Performance assessment; Portfolio

Definition

Many definitions of *authentic assessment* have been proposed in order to distinguish it from other kinds of assessment (e.g., Darling-Hammond et al. 1995; Wiggins 1998). Darling-Hammond et al. (1995) posited that authentic assessment is designed to provide students with opportunities to demonstrate what they can do in a situation that requires the application and production of knowledge, rather than mere recognition or reproduction of correct answers. According to Darling-Hammond et al., authentic assessments are contextualized in students' lives and learning experiences and so well-integrated into the teaching and learning process that they are indistinguishable from instruction.

Despite subtle differences among the proposed definitions of authentic assessment, it is a well-accepted notion that assessment becomes *authentic* when it exemplifies the real-life behaviors and challenges experienced by actual practitioners in the field, rather than merely eliciting easy-to-score responses to simple questions (Darling-Hammond et al. 1995; Wiggins 1998). A widely accepted framework for determining the authenticity of an assessment design was proposed by Wiggins (1998). According to Wiggins, an assessment task is authentic if it (1) is realistic, (2) requires judgment and innovation, (3) asks students to carry out work in the subject, (4) replicates the context in which adults are evaluated in the workplace or personal life, (5) assesses the students' capability to use a repertoire of knowledge and skill to perform a complex task, and (6) allows opportunities to rehearse, practice, consult resources, get feedback on, and refine performances and products. Table 1 contains Wiggins's summary of the key differences between authentic and typical tests.

Evolution of the Term

Early scholarship on authentic assessment was driven by an interest in assessment methods that

Authentic Assessment, Table 1 Key differences between traditional tests and authentic tasks (Adapted from Wiggins 1998)

Indicators	Tests	Authentic tasks
Output requirement	Require correct responses	Require quality product and/or performance along with justification
Pretest/ assessment exposure by students	Must be kept from students to ensure validity	Tasks, criteria, and standards are communicated to students in advance
Connection to real-world	Are disconnected from a realistic context and constraints	Require application of knowledge and skills related to realistic problems likely to be encountered outside of school
Type of knowledge and skill required	Contain items requiring use or recognition of known knowledge or skills	Are challenges in which knowledge and judgment must be innovatively used to produce a quality product or performance
Evaluation	Simplified to be easily and reliably scored	Involve complex and nonarbitrary tasks, criteria, and standards that can yield valid inferences about student learning
Frequency	Usually taken only once	Are iterative, typically including recurring essential tasks and standards
Validation	Depend on highly technical correlations	Provide direct evidence prompted by tasks that have been validated against key discipline-based challenges in adult practices
Result	Generate a score	Provide diagnostic feedback to improve performance and learning

were closer to classroom practice and more naturalistic than traditional testing, which was criticized for failing to measure many of the important aspects of meaningful learning (Chittenden 1991). Proponents argued that authentic assessment could evoke student interest and persistence through the employment of apt, challenging, realistic tasks and produce gains on conventional tests and in student learning (Wiggins 1998).

Archbald and Newmann's (1988) book on authentic academic achievement is often referred to as the earliest work that sought to promote assessment that centers on a variety of meaningful, real-world tasks. Wiggins (1998) brought the idea of authentic assessment to a broader audience through a series of publications advocating the concept and the use of authentic tests or assessments with real-world applications. By the 1990s, the topic had generated substantial interest. Persuaded by Wiggins's claim that understanding is developed and revealed through authentic work, feedback, and the use of knowledge in diverse contexts, educational researchers and practitioners experimented with alternatives to traditional testing (Darling-Hammond et al. 1995).

Initial efforts were stymied by difficulties with creating an operational definition that distinguished between *authentic*, *alternative*, and *performance* assessment. For example, there was some debate about whether *performance assessment* is synonymous with or a component of *authentic assessment*. There is now general agreement that assessment can be performance-based without being truly authentic: A performance assessment is not considered authentic if it does not involve tasks with realistic value (Wiggins 1998).

Another issue in the literature involved the distinction between authentic and alternative assessment. Since the term *alternative assessment* typically connotes any assessment other than traditional paper-and-pencil tests (Fischer and King 1995), authentic assessment usually can be a treated as a concept subsumed by alternative assessment.

Chittenden (1991) argued that terms such as *authentic*, *alternative*, and *performance* assessment are essentially nontechnical placeholders which should be replaced by more functional terms such as *portfolios* and *exhibitions*. This practical suggestion is reflected in the research literature: Since authentic assessment takes a variety of forms, empirical studies focus on a particular type of authentic task such as a *portfolio*, *hands-on laboratory*, *field experience*, *open-ended problem*, *computer simulation*, or *group discussion*. Therefore, although the term *authentic assessment* is still used to indicate a general category of assessment that involves tasks that model and demand important real-world work and elicit performances that allow direct examination of student learning and understanding (Wiggins 1998), more recent literatures tend to use activity descriptions that depict particular tasks and procedures associated with authentic assessment.

Cross-References

- ▶ Assessment of Doing Science
- ▶ Assessment of Knowing and Doing Science
- ▶ Assessment to Inform Science Education
- ▶ Authentic Science

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Authentic Science

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Science is a way of thinking used to develop explanations of natural phenomena using evidence and logic. Authentic science is essentially the same thing, the term only having been coined to distinguish and separate the scientific ways of thinking from classroom science activities that do not, in fact, reflect the spirit and behavior of science. It is argued that traditional experiences in many classrooms charged with teaching about the science disciplines are outdated, in that they do not facilitate the learner in learning to think and behave in the manner of actual scientists. Authentic science is a variation of inquiry teaching that aligns closely with how scientists do their work and differs from traditional school science laboratory exercises (commonly called "laboratories" in the USA). Many traditional laboratory experiences are static and contrived, leading the student to a predetermined "correct" result, often known to the student. This is not to say such educational activities are totally without merit; but this change, from engaging students in experiences in which they already know the answer to engaging students in investigations similar to those conducted by scientists, is overdue.

The term "authentic science" refers to a science experience that embodies more of the qualities of actual or real science. Authentic refers to using data and logic to create an explanation for something not known or understood and using skepticism about the best explanations or applications to society. Authentic science involves engaging students in answering scientific questions currently being investigated by scientists in today's world. Traditional school "science" sometimes does not meet these criteria, and so the term authentic science was created to describe those science activities and experiences that come closer to meeting those standards. The importance of doing authentic science in classrooms is in the outcome for students, that of critical thinking. For example, Bybee (2006) described the way scientists work and think, “How scientists know and explain the natural world and what they mean by explanation and knowledge are both directly related to the processes, methods and strategies by which they develop and propose explanations” (p. 2). Many educators acknowledge that the nature of inquiry that takes place in a scientist’s laboratory differs to a certain degree from school science inquiry. Yet, school children can learn how to construct models and develop scientific arguments much like a scientist does, in developing explanations (Bybee 2006; NRC 2012). Authentic science differs from the view of science many children acquire through their experiences in traditional science classrooms. Making science learning in classrooms more aligned with authentic science practice has been a common goal of educators for over a hundred years. For example, as early as 1910 Dewey advocated that children should engage in authentic inquiry. By engaging students in authentic science, it is assumed that students will learn more about the practices of science (NRC 2012). Many science educators anticipate that if students can experience authentic science, they will become active learners, they will have the opportunity to understand the nature of science, and further, they will become lifelong learners. Yet there has been little progress made in changing classrooms to embrace more authentic science practices. Traditional school labs often give step-by-step directions that prevent the learner from experiencing what it means to think like a scientist. Teachers often disconnect the practices of authentic science from “school science.” Studies show that it is rare for teachers to shape their teaching practice by their declared epistemological beliefs; one reason may be the perceived barriers posed by their school administration and state national policies.

To give students more authentic experience of science, some educators advocate increased use of out of classroom experiences, including visiting scientists’ laboratories. Other experiences include spending extended time in scientific research laboratories. Some educators have suggested that apprenticeships in real scientific laboratories will translate directly into greater understandings of the nature of science. Interestingly, this apparently reasonable assumption is not fully supported by empirical studies.

In revising very structured classroom exercises to be more open-ended thus resembling authentic science, it is hoped that students will come to understand the nature of scientific inquiry and appreciate aspects of the nature of science. One method of integrating authentic science in the classroom involves the use of technology or as termed by cognitive scientists, learning technologies. One example of a learning technology that aligns with authentic science is probeware, equipment that is connected to a computer. Using probeware, children can collect real-time data and make interpretations, much like a scientist, if the lesson involves ill-structured problems and questions with no answer already known to the student.

Authentic science in the science classroom tries to replicate the kind of thinking done by scientists but, to be engaging, is also relevant to students. Authentic science forms a basis for developing effective ways of teaching children science. There have been and remain some critics of this way of teaching. However, its supporters claim that some critics indiscriminately lump many pedagogical approaches – constructivist, discovery, problem based, experiential, and inquiry based – under the category of “minimally guided instruction” (Hmelo-Silver et al. 2007, p. 99). Just moving authentic scientists’ science into the classroom is not automatically effective for students, without some modification of the curriculum and support from teachers. There are various forms of authentic science teaching in the science education literature. For example, some researchers describe their particular authentic approach to science learning as inquiry-based, project-based, or problem-based learning. In each case there is a real-world question or problem that sets up the learning experience.

Recent reforms in science education advocate that teachers engage children in posing and using authentic scientific questions, giving priority to data, using data as evidence in developing explanations and examining alternative explanations, using mathematics, building and using models, developing and using arguments, and communicating and defending explanations (NRC 2012). A fairly recent emphasis in the classroom is a focus on model-based instruction and use of argumentation. Regarding modeling, teachers guide students in building and using models and in learning about the nature of models and how scientists use models. Children engaged in model-based instruction learn how to reason about data and phenomena by using models. In developing students' use of argumentation as used by scientists, teachers support children in interacting with their peers, in discussing and debating their ideas. Children learn how to construct an evidence-based argument and defend it. This kind of teaching demands that a teacher has in-depth understanding of science concepts and principles, in addition to competency in supporting children in discussions of data interpretation, model building, and argumentation.

Authentic science in the classroom enables students to engage in investigations that are meaningful to them and are similar to tasks carried out by scientists (Chinn and Malhotra 2002). There is some empirical evidence that when students engage in authentic science in classrooms, they value the authenticity of the investigation. One example of an authentic science experience is an environmental study of a pond, stream, or river near a school. In this case, students use equipment to collect temperature, dissolved oxygen, turbidity, depth, and other physical parameters. In addition students can learn how to sample and identify the living organisms, such as macro-invertebrates, which serve as water quality indicators. When students analyze these data, they can, with support of the teacher, develop a model of the pond, stream, or river and make predictions. These data can be collected over several years to track changes in water quality over time. Although students realize that they themselves are not trained scientists, when carrying out similar kinds of authentic activities, they believe they can contribute meaningful data for others.

Authenticity can also provide a meaningful context within which children can actively reflect on aspects of nature of science (Schwartz and Crawford 2005). When students engage in authentic science in a classroom community, they can participate in social practices similar to those of a scientific community. Participation in a modeled authentic scientific community can help make science accessible to students of diverse cultures and students from populations not usually represented in the scientific community. There is an expectation that authentic science in classrooms can and will motivate students. However, more research is needed to determine the extent to which authentic science may increase an interest in learning science, in students of underserved populations.

Cross-References

- ▶ Inquiry, as a Curriculum Strand
- ▶ Laboratory Work: Learning and Assessment

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Beliefs

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The concept of “belief” is frequently contrasted with the concept of “knowledge,” where in everyday language “knowledge” is thought of as “reasoned belief” that a proposition is true. One can understand a concept, for example, evolution, while believing the concept either to be true or false. Belief is a personal, subjective affirmation or rejection of the truthfulness of the proposition. Hence, belief and knowledge do not stand in opposition but work in conjunction (Cobern 2000; Quinton 1967). Because these concepts work in conjunction, it is also inaccurate to refer to things that are believed as opposed to things that are known. When belief and knowledge are contrasted in this way, it is typical for belief to be thought of as “blind” belief, in other words believing something to be true without any evidence or reason. However, no one holds a belief for no reason; it is just that there are many varieties of reason. For example, one may believe a proposition of science to be true because of the experimental data provided by a scientist in support of that proposition. That being said, a person may not be informed well enough to understand the evidentiary base for the proposition, but the person trusts in the authority of science. In this case, what is believed to be true is not blind belief but belief based on authority. Controversy arises however because not all authorities are equally trusted by all persons. Therefore in any discussion of belief, it is always important to understand the reasoning that is used in support of the belief (Stenmark 1995). Similarly, it should not be assumed that knowledge of something is the same as believing something to be true.

Cross-References

- ▶ Attitudes to Science and to Learning Science
- ▶ Attitudes Toward Science, Assessment of
- ▶ Cultural Change
- ▶ Curriculum and Values

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Bildung

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Introduction

The concept of *Bildung* is a major influence on discussions about, and reflections on, educational goals in the German-speaking countries and other Northern European countries with a similar cultural and linguistic background. *Bildung* in this regional and linguistic context is the central notion describing the process of personal development and the outcome of this development process. *Bildung* is more than education, and there is no English term that denotes the concept of *Bildung* accurately. Nonetheless, it may serve as a bridge between two educational traditions when an American educational researcher proposes the following explanation of the meaning of *Bildung*:

> *Bildung* is a noun meaning something like 'being educated, educatedness.' It also carries the connotations of the word *bilden*, 'to form, to shape'. *Bildung* is thus best translated as 'formation', implying both the forming of the personality into a unity as well as the product of this formation and the particular 'formedness' that is represented *by* the person. (Westbury 2000, p. 24)

This might function as a first orientation but it will be clear from the following text that the term "formation" runs the risk of being misinterpreted as a one-sided process.

Historical Roots

In 1784, the philosopher Immanuel Kant began an essay on the question "What is Enlightenment?" with the much-cited sentence: "Enlightenment is man's emergence from his self-imposed immaturity." Scholars of different disciplines adopted this idea and adapted it to their specific area of expertise. It became closely interwoven into the idea of Bildung.

Among these scholars the philosopher of language, anthropologist, neo-humanist, and Prussian politician Wilhelm von Humboldt reflected on consequences for the phase of human beings' growing up. According to von Humboldt's ideas, neither adolescents' alignment to the demands of society, where criteria like usefulness and efficacy play a dominant role, nor their growing up free from cultural influences in the sense of Rousseau should be the guideline for the process and the state of *Bildung*. Von Humboldt combined both aspects and advocated a balance between them, stating that "the true purpose of humans is their highest and most proportional cultivation of their strengths as a whole." An indispensable condition for this development is civil liberty and, connected with liberty, diversity of situations. These situations are defined by cultural and societal characteristics. In von Humboldt's world there is no individuation without cultivation. In his idea of *Bildung*, the individual and humanity are two facets that are strongly interrelated to each other.

In the 1790s, von Humboldt argued that the ultimate task of life is to endow the concept "humanity" with as rich a content as possible. He believed that this could only be done by associating with the world in the most comprehensive, lively and freest interplay possible. This statement is an early formulation of a characteristic feature of our modern time, i.e., the necessary and paradoxical concurrence of the processes of cultivation and individuation. Or as Immanuel Kant, the great apologist of the idea of liberty, put it shortly after von Humboldt:

> One of the most serious problems of education is how to combine the individual's subjection to the legal constraints with the ability to use his/her freedom ... How can I cultivate liberty with this restraint? (Kant 1803, p. 711)

According to Nordenbo (2002), "*Bildung* seeks to bring the unique individuality into a harmonious relationship with general objectivity" (p. 350). For von Humboldt, the people of ancient Greece were classic examples of humans struggling for a harmonious relationship between the individual self and the world; therefore, he preferred the ancient languages Greek and

Roman as paradigmatic media offering appropriate access to *Bildung*. This preference was one of the reasons for the restriction of von Humboldt's ideas to the Prussian High School (Gymnasium) and for a lengthy debate about the suitability of different school subjects like mathematics or arts for achieving the goals of *Bildung*. Natural sciences were not regarded as a domain contributing to *Bildung* because of their usefulness in the century of industrialization. Members of society who were interested in the integration of the natural sciences into the school curriculum – pedagogues and politicians with a scientific background, representatives of industry and economy – emphasized the potential influences of these subjects on students' *Bildung* in the sense of Humboldt. In Germany, it took about a hundred years until the natural sciences were integrated into the school curriculum of the higher educational institutions (e.g., the Gymnasium), on an equal footing with the subjects already established. In the end, two kinds of pedagogical justification have been responsible for this integration: the traditional idea of *Bildung* (natural sciences are part of the efforts of humans to understand themselves in relation to the world around them) and the demands set by the society which expects the school to lay the foundation of expertise among as many members of society as possible, in order to meet the requirements of a technically oriented world. This twofold rationale nowadays constitutes the framework for all discussions and decisions concerning the structure of the curriculum in all school types.

A Modern Approach to *Bildung*

The different educational contexts within the historical development of the societies in which the concept of Bildung played a significant role led to various shifts in the meaning of *Bildung*. Wolfgang Klafki, the most prominent educational scientist seeking to develop for a modern understanding of *Bildung*, draws on ideas and descriptions presented in the decades around 1800 and points to their most significant features. For him, one of the most fundamental ideas that emerged at this time was the idea of the self-responsible, cosmopolitan person, contributing to his own destiny and capable of knowing, feeling, and acting. For Klafki (2000), the terms "self-determination, freedom, emancipation, autonomy, responsibility, reason, and independence" (p. 87) are crucial notions in relation to Bildung. But this is only one side of the overall meaning of *Bildung*. Klafki also stresses that this list of concepts could be misinterpreted as a description of *Bildung* as an individualistic conception; so he adds: "…the basic concept of subject- or self-determination is anything but subjective!" (p. 88). *Bildung* is also characterized by a second group of factors: humanity, humankind and humaneness, world, objectivity, and the general. *Bildung*, therefore, develops in the interplay between individual attributes, achievements, and expectations on the one hand and the conditions a person has to cope with on the other. These conditions are results of societal processes and comprise different kinds of social life as well as systems of norms and beliefs that pertain to the fields of politics, arts, science, and other domains. The interplay described mirrors a more differentiated process than Westbury's notion of "formation" can reflect.

In Klafki's view, the societal part of this interplay described has been not sufficiently analyzed by those who strive for a widely accepted conception of *Bildung*. He writes that "… the economic, social, and political conditions needed for the realization of this general demand for Bildung" (p. 89) were not examined consistently. In order to adjust the traditional conception of *Bildung* to the characteristics of individuals' contemporary environments, Klafki (1998) points to the direction in which the development of a modern version should be heading. At the core of these processes should be elaborated "a more differentiated and critical determination of the relationship between Bildung and society" (p. 313). Three abilities were, in this way, to be promoted by *Bildung*:

- Self-determination
- Codetermination (all people are invited to take part in the development of the society)
- Solidarity (with those whose opportunities for self-determination and codetermination are limited)

Bildung, as a process and its result, has to be permanently balanced between an adolescent's self-determination and his/her conformation to the demands of society. The German word "Erziehung" and the English word "education" are often used with the connotation "preparation for the demands of society." Therefore, "education" (like "Erziehung") covers only a part of the considerably broader spectrum of features that are characteristic for *Bildung*.

Variety

Because of the lack of a generally held understanding, there is a vast variety of contexts in which the notion of *Bildung* is part of the pedagogical and political discourse and of meanings that are linked to the term. Especially in public discussions, *Bildung* is reduced to become almost synonymous with "education." On the level of politics, the notion of *Bildung* has got such a general connotation that an interpretation is almost impossible. The German ministries that are responsible for the organization and structure of the educational systems (schools, kindergartens, vocational schools), and for the content-related issues within these systems, are ministries of *Bildung* although their political decisions mainly refer to the functioning of the state-run institutions. Because of this indistinct use of the term, the leading German theorist of *Bildung*, Tenorth, commented that *Bildung* can be regarded as a German myth, a pedagogical program, a political slogan, and an ideology of bourgeoisie. Often the term is used in connection with criticism of current society. In the light of this variety of meanings, does it make sense to use the term *Bildung* when any speaker or writer is likely to have a different conception in mind from that of the listener or reader? In Tenorth's view, *Bildung* still has great potential for describing the goals and processes of human growing up, especially if empirical aspects are integrated into the reflections on *Bildung* that have been shaped by mainly philosophical arguments.

Bildung and Scientific Literacy

In spite of the lack of a generally accepted understanding of *Bildung*, at least the core of the concept becomes clearer when it is compared or contrasted with the way the term "scientific literacy" has often been used in the last two decades. On the international level, in the OECD PISA project, scientific literacy focuses on the application of knowledge in science and so has a more functional connotation than *Bildung*. This interpretation of scientific literacy becomes visible in the statement of the OECD that the cognitive aspects of students' scientific literacy include students' knowledge and their capacity to use this knowledge effectively. The idea behind this statement is that education should prepare students for the demands imposed on them during their whole life. This idea becomes clearer in the OECD's more precise affirmation that the PISA tests cover scientific literacy, not so much in terms of mastery of the school curriculum, but in terms of important knowledge and skills needed in adult life. The conception of *Bildung* does not ignore the task of helping adolescents deal with the challenges of their future life. However, this educational aspect is embedded into a more holistic view, where universal principles like rationality, humanity, and morality are interwoven with an individual's growing up.

The dominant position of the term "scientific competency" in the description of the PISA program signals additional differences between *Bildung* and scientific literacy. As discussed above, the functional aspects of students' knowledge (competencies and skills) contrast with the concept and process of *Bildung*. So, for example, a phrase like "We teach children to be competent in a special domain," due to its one-sidedness, is not in line with the concept of *Bildung*. *Bildung* cannot be interpreted as the European version of scientific literacy, and in the process of selecting topics for the school curriculum, the question "Is it useful knowledge?" could be a guideline at best of secondary importance. An individual's knowledge and competencies represent only one facet of *Bildung*; another points to the individual's efforts to find his/her place in the rational, humane, scientific, and esthetic world. One of the most distinguished contemporary German pedagogues Hartmut von Hentig, well known as an author of fundamental reflections on *Bildung* and as a school and university teacher, has condensed these two facets into a depiction widely accepted: *Bildung* describes the tension or the bridge between ideals passed on and current needs of competence, between philosophical self-assurance and the practice-oriented self-preservation of society. In Plato's allegory of the cave, *Bildung* is both the rise towards sunlight and the descent towards the cave. The one without the other makes no sense.

Bildung Within Natural Sciences

Martin Wagenschein (2000) and other scholars have discussed how students' *Bildung* in natural sciences can be achieved. For Wagenschein, the main goal of science education is to help students understand phenomena of the natural world. To "understand" means to have gained insight into the essence of scientific relationships; it does not mean just to know the formula or to be able to apply it to a concrete problem. According to Wagenschein, there are three characteristic teaching-learning situations in which *Bildung* in this sense can develop:

- *Exemplary teaching*: In order to gain a deep understanding of a piece of content, it is necessary to invest a sufficient amount of time. Therefore, "we need the courage to leave gaps, in other words to be thorough and to deal intensively with selected examples" (Wagenschein 2000, p. 116). These examples have to be representative of the domain (its topics or methods) and at the same time exemplary as regards their contribution to students' *Bildung*.
- *Genetic teaching*: If the knowledge is to become an integral part of a student's Bildung, it is important that he/she has the opportunity to search productively for the solution of a problem, to find it, and to check it critically. From this perspective, Wagenschein, in the early 1950s, introduced elements of an idea that later, in its cognitive dimension, became known as the constructivist view of learning. Wagenschein emphasized the development of knowledge as much more than the result of the process of acquiring knowledge.
- *Socratic teaching*: A teaching-learning process which focuses on the development of knowledge is best arranged in a Socratic conversation. The teacher has to talk with his/her students not in a lecturing and dogmatic way but, like Socrates in his dialogues, focusing on their ideas and moderating their learning processes.

According to Wagenschein, teaching environments with this triad of principles are particularly suitable (and often necessary) for learning episodes in which a basic understanding of central notions and processes in natural sciences is to be acquired. This is the case especially in upper grades of elementary school and in lower grades of secondary school. However, Wagenschein's triad is meant to be effective at all levels, since the process of *Bildung* does not come to an end. Examples from physics and chemistry education (and a fuller discussion of several of the ideas discussed above) can be found in Fischler (2011).

Critics of Wagenschein's view of teaching and learning complain that it is too time-consuming and, because of its exemplary character, about students lacking knowledge, that they need to systematically build up concepts of natural sciences. But there is no strict alternative, no either/or. Students have to get to know the basics of natural sciences as a cultural domain of mankind and to have the chance to achieve this goal on the way of exemplary, genetic, and Socratic teaching and learning.

Cross-References

- ▶ Curriculum and Values
- ▶ Didaktik
- ▶ Scientific Literacy

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Biology Teacher Education

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Keywords

Biology; Teacher professional development

What Is Unique to Teaching of Biology? What Are the Problems and Challenges?

The education of biology teachers, like those for their counterparts in other science disciplines, typically pays attention to common and key issues such as teaching of scientific inquiry, nature of science, and dealing with students' alternative ideas, etc. – the ultimate goal being to develop in teachers the pedagogical content knowledge necessary for effective teaching of science in general and biology in particular.

First, biology is the study of life and its evolution. Indeed, evolution is increasingly used as one of the unifying concepts in developing school science education standards around the world. However, for different reasons, not all biology teachers embrace the notion of teaching evolution in schools (Bybee 2004).

Second, many advances in biology are based upon experimental results and accurate observations in the field. In other words, fieldwork is a key component in understanding biology. However, there has been a decline in fieldwork in schools. One major reason is the insufficient preparation of biology teachers for teaching in the outdoors, teaching in nature (Barker et al. 2002).

Third, biology teachers need to be able to help their students discuss bioethics and the societal implications of biology. They are also expected to help students undertake a range of activities which can help them to develop criticality and to enhance their potential for action. This new vision of biology education for action as well as for knowledge and understanding presents additional challenges for biology teacher education (Zeidler 2003).

How Can Teachers Be Prepared for the Challenges?

Addressing issues of teacher preparation to teach evolution should begin with an assessment of their attitudes, perceptions, and confidence for teaching evolution. Results from surveys suggest that the importance and relevance of evolution to the school science curriculum may need to be explicitly addressed in the education of biology teachers. However, given the politics of teaching evolution in schools (in some countries) and the complexity of the issues involved, a quick solution to this problem is rather unlikely.

To develop critical thinking about societal issues and to enhance the potential for action, students need to be able to analyze scientific information critically as well as to apply it to real world issues. To prepare teachers who can guide instruction of this type, reform of preservice teacher education has been a constant over the past two decades. Promising results were reported by some programs. In these programs, preservice teachers were engaged in identifying research questions where their knowledge of biology could be applied to solving real-life problems. Besides learning how to make informed decisions about science and technology issues in real-life contexts, the preservice teachers were also asked to look into their pedagogical practices to determine the techniques that could be employed to help learners (students) appropriately apply biological knowledge. Hence, through the experience of their own science investigations based on real-life issues, the preservice teachers are given opportunities to learn the various ideas about the pedagogy of science teaching and learning.

Preservice teachers rarely get to prepare and practice teaching in the outdoors in their methods courses or during their practicum. To address this problem, examples of engaging student teachers to actively conduct field trips and having part of their teaching practicum attached to outdoor environments (such as an aquarium or eco-garden) are beginning to emerge. Results show that actual teaching in an outdoor environment empowers teachers and provides them with positive experiences that impact implementation of future outdoor teaching. Results also indicate that teachers should play different roles, rather than traditional ones, in order to function effectively in out-of-school settings. Furthermore, these studies illustrate the potential of reimagining and re-/forming preservice programs to incorporate practicum experiences that go beyond classroom settings. This helps preservice teachers expand their views of biology teaching and learning beyond the boundaries of the classroom-based environment and provides firsthand experience to equip them to move beyond textbook-based biology teaching.

To conclude, while there are commonalities between education for biology teachers and their counterparts in other science disciplines, there are also unique features (as outlined above); some of which require ongoing attention in order to lead to the improvement sought by biology teacher educators more generally.

Cross-References

- ▶ Chemistry Teacher Education
- ▶ Curriculum in Teacher Education
- ▶ Environmental Teacher Education
- ▶ Excursions
- ▶ Pedagogical Content Knowledge in Teacher Education
- ▶ Pedagogy of Teacher Education
- ▶ Physics Teacher Education
- ▶ Science and Society in Teacher Education
- ▶ Secondary Science Teacher Education
- ▶ Teaching Science Out-of-Field

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Biology, Philosophy of

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Keywords

Biology

William James distinguishes between tender-minded philosophers and tough-minded philosophers. No one would use tender-minded as a term referring to Aristotle, the first and the best of philosophers to look at biology, but it does seem true that in the millennia succeeding (especially since the scientific revolution) biology has attracted thinkers who do want to find meaning and comfort in the material world and its explanations. Vitalism, holism, and emergentism were the terms commonly favored.

Things started to change significantly about 50 years ago, when a small group of analytically trained philosophers, including David Hull and Michael Ruse, turned their attentions to the biological sciences, determined to bring understanding and rigor to meta-analyses of the life sciences (Ruse 1988). Today, philosophy of biology is one of the strongest and most popular areas of Anglophone philosophy, with related interest in other academic cultures.

For fairly obvious reasons, evolutionary theory has attracted most attention. It is a topic that raises many issues, for instance, theory structure, the nature of laws, the problems of causation, making claims about past events, many of which were unique, and much more. However, in recent years more and more attention has been paid to related and other areas of the life sciences, including molecular biology, ecology, systematics, and human biology, with special reference to culture and the ways it changes and its interactions with the underlying biological base (Ruse 2008).

Almost all philosophers who have looked at the evolutionary theory have been deeply committed evolutionists. However, in recent years a small group of vocal Christian philosophers, notably Calvinist Alvin Plantinga (2011), have been arguing that so-called intelligent design theory – supposing occasional, nonnatural, important changes – has much to commend it. There is also in such circles considerable doubt about the major claims of paleoanthropology, namely, that humans evolved from apelike creatures, in Africa, breaking free about five or six million years ago, and never were a population less than at least 10,000 members. The critics worry that this kind of thinking is incompatible with the creation story of Adam and Eve in the book of Genesis, and with the subsequent Fall, something thought undeniable for the Christian faith.

Philosophers accepting evolutionary theory have their own controversies, generally focusing on the adequacy or otherwise of the Darwinian account of change, an account that privileges natural selection (the survival of the fittest) as the major cause of change. No one denies that natural selection – the differential reproduction of organism, with consequent success for some with useful variations and failure for others without such variations – has a role to play in the evolutionary process. Intended to speak directly not just to change but to change of a particular kind, namely, adaptive or design-like change, the existence of organic features that used to be known as “final-cause” features, because they serve organisms’ needs or ends – features like hands and eyes, bark and leaves, and hunting ability and defense mechanisms – cries out for a selection-fueled origin.

But how universal is adaptation? Are all or virtually all features of animals and plants adaptive, or is adaptation the exception rather than the rule? Take, for instance, something like the facial hair of human males. Does this have an adaptive role to play, for instance, in keeping men warm (in which case, why do women not have beards) or in sexual attractiveness (in which case why are some human races relatively facially hairless), or is the case rather that facial hair is a by-product of other things, namely, hormones required for the production of male genitalia and so forth, and so in itself has no adaptive function at all.

The philosophically inclined biologists Richard Lewontin (a geneticist) and Stephen Jay Gould (a paleontologist) made much of the supposed nonadaptive nature of many organic features, referring to them as “spandrels,” meaning that they are simply part of the architecture of organisms and selection played no role in their production (Gould and Lewontin 1979). Gould particularly was prepared to state that the Darwinian obsession with what he called “pan-adaptationism” was a relic of earlier natural theological beliefs about God’s omnipotence in designing the universe and its contents and as such should have no place in modern secular science.

A related debate has revived the relevance of James's tender-minded/tough-minded dichotomy, for there is much concern about the way in which natural selection operates when it is clearly active. Obviously much that selection does is directed to the benefit of the individual. My eyes are for me to see, not for you to see. But not everything works quite this way. The mammary glands of mammals – breasts, teats, and so forth – are for the benefit of the offspring, not the mother (ignoring possible dual roles like sexual attraction). In a case like this however, since selection operates to promote reproduction, inasmuch as the offspring thrive, the mother's ends are met. But what about nonrelatives? Can selection in one organism promote features that will be of benefit to other organisms? There has been much heated philosophical debate on this subject, with some claiming that selection always acts primarily for the individual and others that it can frequently promote the good of the group, even at cost to the individual. It is clear that much that motivates supporters of "group selection" is a strong dislike of the selfishness of "individual selection," where organisms are seen in a constant struggle of one against all. Nature, such tender-minded thinkers claim, has a gentler, softer side to it. Nature, as the tough-minded thinkers respond, cares nothing for niceness. Thomas Hobbes was right – life is "solitary, poor, nasty, brutish, and short."

Is the philosophy of biology relevant to – or particularly relevant to – science education? Many think that it is and few would want to deny this entirely. On the one hand, a strong case can be made for saying that as soon as the science teacher goes beyond the collecting or observing of particular objects and facts and starts to move towards understanding, philosophy necessarily enters in. One is going to start talking in terms of generalities, laws, and means of explanation, models and hypotheses and theories, and all of this is by its very nature philosophical. In teaching biology, the philosophy of biology has an obvious and essential role.

The following are three examples. First, the student having taken a course in physics where final-cause language is barred – no one asks the function of a volcano or of the moon – wonders why such language is not just allowed but happily and positively permitted in biology, you talk about the function (or nonfunction) of the leaves on a tree or of the appendix in humans. At once one is plunged into metaphors about design and whether a mechanism like natural selection can speak to them. Second, the student having taken a course in chemistry, where substances tend to be substances and no argument, comes to biology and finds that species have all sorts of boundary problems and higher orders like genera are very subjective and fluid. Are modern humans and Neanderthals one species or two, and why? At once one is plunged into all kinds of debates about classification and natural and artificial systems. Third, the student having taken a course in genetics where DNA rules now looks at ecology and wonders what on earth the molecules have to do with the nature of things. What do molecules have to do with the fish in a lake? At once one is plunged into discussions about the relationships between different levels of understanding and whether claims at one level can be explained by, "reduced to," claims at other levels and whether this should always be the aim of science.

On the other hand, in America particularly, but increasingly in other countries, there are those who would constrain or oppose biological understanding for religious reasons. Increasingly this is happening across the board, from evolutionary theory to biomedical technology. Focusing just on evolution, philosophy can and has played a major role in defending the integrity of science. In the past few decades, there have been a number of court cases in America where religiously minded politicians and others have tried to introduce biblically inspired accounts of organic history into state-supported science classes – in Arkansas in 1981, in Louisiana later in that decade, and in Pennsylvania in 2005. In all of these cases, philosophers played an important role in articulating the nature of good science and then showing that modern evolutionary biology, for all its controversies, qualifies as good science, whereas biblically inspired accounts – be they so-called creation science or intelligent design theory – not only are not good science but fail to qualify as science at all. At best they are religious wolves in scientific sheep's clothing, trying to get around the First Amendment separation of the church and the state (Pennock and Ruse 2008).

Philosophy of science is in major respects molded and shaped by the science itself, and as the science changes and develops, so the philosophy likewise changes and develops. The past 50 years have been exciting times for biology, molecular and organismic. The same has been true of philosophy of biology. One expects biology to keep up the same exciting pace of change and development. The same will no doubt be true of the philosophy of biology, and, if anything, its relevance to science education can only grow and deepen.

Cross-References

- ▶ Chemistry, Philosophy of
- ▶ Context of Discovery and Context of Justification
- ▶ Epistemic Goals
- ▶ Mechanisms
- ▶ Models
- ▶ Representations in Science
- ▶ Science Studies
- ▶ Scientific Visualizations
- ▶ Social Epistemology of Science

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Black or African Ancestry

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An examination of Black ancestry provides insight into both US history and world history. From a historical perspective, Black Americans are the only racial/ethnic group that came to the United States of America initially as involuntary immigrants. Much of their African ancestral language and cultural traditions were destroyed after two centuries of enslavement and bondage. Africans represent a myriad of ethnic groups with over 800 languages. From a more modern perspective, primarily the miscegenation between Africans and Europeans and Africans and Native Americans resulted in the ethnic group more currently identified in the United States of America as "Black Americans" or "American Americans." Furthermore, Black Americans in the United States of America, though descendants of Africa, do not identify with the culture, language, and traditions of their African ancestry since much of their history has been defined on US soil through a lens of westernized culture.

Black ancestry can be characterized through a plethora of historical turning points in US history (i.e., slavery, Civil War, Emancipation Proclamation, Jim Crow, etc.) as the United States of America transitioned from slavery states to free states. It is well known that the largest number of slaves in the Western Hemisphere was in the United States of America, and the gradual transformation from the African identity to the African American identity society that is most familiar with today reveals juxtaposition that has been the source of much internal struggle or conflict.

African Ancestry

The African Diaspora characterizes African ancestry that emerged out of both the voluntary and involuntary migration of Africans throughout the world. The slave trade made the African presence global starting with their capture and enslavement that existed among ethnic groups in Africa, ancient Greeks, and Romans. At least 1,500 years before the Europeans participated in the trade of African slaves, the Arabs (the first mass enslavers of Africans) conducted slave trades of Africans throughout the Sahara Desert, Mediterranean Sea, Indian Ocean, and Red Sea transporting Africans to India, Arabia, and the Far East (Harris 1996). Even with the cruel and inhumane treatment of Africans, many arrived abroad and preserved their languages and traditions calling themselves Africans and Ethiopians. Hence, the African Diaspora refers to what is considered a triadic relationship between Africans as a dispersed group of people back to their homeland and their adopted or host countries (Harris 1996). Even though Africans were enslaved in many places around the world, many valued family and community, preserved cultural traditions, and learned European languages and advanced technology.

Race

Race is socially constructed and has no biological basis as a racial identification and classification. Simply put, there is no Black, White, or Asian gene; technically, there are more genetic differences within a supposedly racial group than across or between groups in order to protect genetic diversity within a group of people. The term “Black” or the notion of “Blackness” emerged as a racial category in Europe and was embraced in the United States of America after the forced relocation of West Africans to the Western Hemisphere. Consequently, the history of Blacks in the United States of America has been largely defined through the lens of Western racism and oppression and has caused a legacy of social, psychological, and economical damage. Specifically, Black Americans in the United States of America have been marginalized and considered a largely “homogenous” group of people, although there is a tremendous amount of diversity within the ethnic group. Even though US history identifies Blackness with a mark of inferiority, the most recent evidence on the origin of *Homo sapiens* points to a single genetic lineage that can be traced back to Africa within the past 200,000 years.

Science

The word “science” in this entry refers to the natural sciences, i.e., biology, chemistry, physics, and geology. The term “science education” refers to the discipline that deals with issues of learning, teaching, curricula, and assessment/evaluation of science in K-14 settings. Due to sociocultural-historical events, people of African ancestry either have not been allowed or few now pursue postsecondary degrees in the natural sciences or science education.

Even though enrollment of international students continues to be critical to the success and diversity of US graduate programs, the relative dearth of students of color in graduate programs is particularly troubling in light of the changing US demographics. Demographers predict that the largest increases in growth among US citizens will continue to be Latinos, African Americans, and Asian Americans. People of African ancestry are 12 % of the US population and 11 % of all students beyond high school; the following percentage of Black high school graduates completed the following science courses: 93.6 % biology, 63.6 % chemistry, 25.8 % physics, 62 % biology and chemistry, and 21 % biology, chemistry, and physics (Aud et al. 2010). Yet in 2009, they received only 7 % of all STEM bachelor’s degrees, 4 % of master’s degrees, and 2 % of Ph.Ds. (National Science Board 2012). In 2008, 824 Blacks out of 48,802 received doctorates in science and engineering (National Science Foundation 2009), while in 2009, only 88 Black males (1.3 %) out of 6,957 received Ph.Ds. in the biological and biomedical sciences.

Historical and Social Factors

These low numbers are the result of complex historical-sociocultural factors from self-doubts, stereotypes, discrimination, oppression, and economics. Arliner Roger Young, a zoologist, was the first African American woman to receive a Ph.D. from the University of Pennsylvania in 1935 professionally published in the field. She had to deal with gender, race, and educational barriers of her time which were no small matters. Unfortunately, she died on November 9, 1964 in New Orleans, poor and alone (Hodges n.d.). In 1943, Lloyd Noel Ferguson was the first African American male to receive a Ph.D. from the University of California, Berkeley, in chemistry and authored more than 50 journal articles and seven textbooks on cancer chemotherapy, the relationship between structure and biological activity, and the chemistry of organic compounds and properties such as odor and taste (Morris 1992).

With segregation legal in the United States of America for many years, it was difficult for Blacks to pursue degrees in the sciences and even more difficult for them to gain employment. Those who obtained science Ph.D. in the early years usually gained positions at Howard University. When segregation was no longer legal in the United States of America, many traditionally White institutions (TWIs) fought against desegregating its student body. Even today, many Blacks cannot pursue science degrees because they do not meet the entry requirements of TWIs. However, progress is being made by those Black students who receive quality precollege education that allows them to meet entry requirements to pursue science degrees even though the cost of postsecondary science education remains to be prohibitive for many.

Present Major Challenges at the Precollege Level

Based on international, national, and state science achievement scores, the quality of K-12 science student learning varies. In the United States of America, suburban, middle class K-12 Asian and European American students perform better on standardized test than other student groups. These test scores usually are used as indicators of the quality of student science learning. Even though differentiated teaching is encouraged, the practices of “grouping by ability” and tracking continue to occur in US schools. These practices give students different access to school resources such as certified teachers with advanced science degrees, updated science textbooks and other curricular materials, and modern science laboratory equipment and materials and opportunities to participate in other science enrichment programs such as summer science programs, after-school science programs, and field trips to museums and zoos.

Science is a way of knowing; the key to understanding science is to grasp the language of science and education The native language of students influences their opportunities for quality science learning because it (a) structures both students’ and teachers’ science learning and (b) determines how they use the language to understand and communicate their understanding of natural phenomena. If the language of science is truly understood, it helps the learner to engage in deductive and inductive reasoning, make hypotheses, generalize research findings, connect evidence to theses, and persuade others. Home language, instructional language, and science language problematize science learning because students must move across communities of family, school, and science. This is especially true when students’ home language is not the same as their instructional and science languages. Since language is a part of students’ culture, it has been suggested that students’ limited adeptness in English restricts their science learning and performance when instruction, assessment, and evaluation are done exclusively or predominantly in “standard English.” Hence, students who are Black English language learners (ELLs) such as Haitians do not perform as well as students whose first language is English. However, when the Black language dialect of African-Americans is used by physics teachers, these students build new physics understanding (Elmesky 2001).

To encourage learning in some groups, adaptations are made for different groups of students. Unfortunately, large numbers of Black students are found in “special education classes” in which few adaptations such as (a) altering the directions, assignments, and testing procedures and (b) including more activity-oriented lessons occur. According to Moje et al. (2001), compatibility among literacy, science learning, and language in diverse classrooms requires four interrelated classroom interactions. Science teachers need to (a) draw from students’ everyday languages and understandings, (b) develop students’ awareness of those various languages and knowledge bases, (c) connect student everyday understandings and languages with the science language of science classrooms and of the science community, and (d) help students to negotiate understanding of both languages and understandings so that these understandings not only inform each other but also merge to construct a new kind of language and understandings.

The science teaching force in the United States of America does not reflect the K-12 student population. In 2007, 45 % of the US K-12 students were Blacks, Latinos, Asian/Pacific Islanders, native Americans, and Alaskan natives (Hussar and Bailey 2011), while in 2008, 21 % of students aged 5–17 spoke a language other than English or spoke English with difficulty (Aud et al. 2010). However, only 7.8 % of the elementary and secondary teachers in 2008 were Blacks, native Americans, Alaskan natives, and Asian and Pacific Islanders (School and Staffing Survey 2008). Haberman (1996) maintains that urban teachers are successful if they have experiences similar to their students such as tragedy in the form of the death of a loved one; critical, life threatening injuries to family members; violence at home; serious unforeseen injuries; poor nutrition and sleep habits; or mental and emotional problems.

Present Major Challenges at the College Level

Blacks are about as likely as White freshmen students to declare science and engineering fields as majors, and Blacks who enroll in or graduate from college are about as likely as Whites to choose science and engineering fields (National Science Board 2012). However, Black females are more likely to complete undergraduate degrees than males (Harper 2012) and more likely to obtain bachelor degrees in biology. Once Black students enter a college or university to major in the sciences, they have additional challenges such as high school preparation, financial support, and the lack of mentoring. If they enter a traditionally White university, additional coping skills are needed to deal with the university’s culture. Even if these Black students graduate with a science degree and pursue doctorates, they continue to have challenges such as having the lowest rates of research assistantships and research publications (Council of Graduate Schools 2012).

People of African ancestry will continue to be challenged to experience equitable science learning and teaching and to contribute to scientific fields. But as in the past, Blacks in the future will continue to enhance the world’s understanding of natural phenomena and to utilize those understandings to better the lives of all human beings in novel ways. Blacks have made tremendous contributions to science, and though presently there are more of them in the biological and physical sciences, their representation in degree programs and careers is still sparse compared to other US groups. In order to increase their numbers, more must be done to overcome the legacy of racial and social inequities that still persist today in the United States of America and the world.

Cross-References

▶ Asian Ancestry
▶ Cultural Influences on Science Education
▶ Cultural Values and Science Education
▶ Latino Ancestry
▶ Pacific Island Ancestry

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Blogs

▶ Blogs for Learning

Blogs for Learning

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Keywords

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Blogs for Learning

A blog is an online space where individuals can publish any form of written work, such as reflections, as a sequence of entries that are often presented in reverse chronological order. In most cases, anyone with Internet access and access permissions can read blog entries and leave comments, which allows interactive communication between writers and readers. Blogs are used widely across the Internet as a means of informal publication and commentary and have also been applied within education communities as a teaching and learning tool to help students develop a range of skills. For instance, blogs can provide rich opportunities to improve students' writing skills. Blogs can create collaborative learning environments that enable students to share various ideas and perspectives, not only with their classmates, but also with a broader audience. Blogs also allow teachers or peers to assess student progress at various stages of instruction and provide timely feedback. Recently, researchers have begun to explore the benefits of such ongoing and iterative written reflections for students' learning. For example, Alexander Renkle and his colleagues (Glogger et al. 2012) have developed a program of research to study the effects of journal writing as a follow-up activity of classroom instruction in helping students reflect on what they have learned in the classroom and identify areas for improvement.

Blogs have the potential to create unique learning opportunities that encourage students to write longer accounts of scientific phenomena than typical short response items and facilitate iterative refinement — important yet often ignored elements of science instruction. For instance, blogs can be implemented in science instruction as a journal that allows students to continuously add their own ideas or other evidence they have discovered about scientific phenomena across topics and grade levels. As students progress through instruction, they can generate, reflect on, and organize their growing repertoire of ideas. Students can also monitor their own progress by reviewing the history of their writing entries and iteratively refine their ideas. Such opportunities could help students develop a more sophisticated understanding of complex science concepts and make connections among various science topics.

To take advantage of blogs for science learning, teachers need to carefully create activities and prompts that engage students and facilitate reflective, iterative writing processes. One instructional strategy is to embed blogs within inquiry activities. Inquiry-based instruction challenges students to develop a deep understanding of scientific concepts through scientific practices, such as making predictions, designing experiments, collecting evidence, analyzing data, and articulating their ideas. This approach requires students to constantly reflect on their learning progress and integrate multiple ideas and perspectives to develop a coherent understanding. Blogs could be used to support students through this process by keeping track of their evolving understanding in the form of written artifacts.

One example of reflective writing in a technology-enhanced inquiry approach is found in the student-generated explanatory narratives, called Energy Stories, employed by the Web-based Inquiry Science Environment (WISE – see Slotta and Linn 2009). Energy Stories prompt students to write a coherent story about energy concepts within a system by making connections among various energy ideas, such as energy sources, energy transformation, and energy transfer. For instance, seventh-grade students wrote Energy Stories about how a rabbit gets and uses energy from the sun across two WISE units in life science (Ryoo and Linn 2012). Students were asked to incorporate all the information from instruction, as well as evidence collected from visualizations, to write coherent narrative accounts of where energy comes from, how energy is transformed, and where energy goes. Students wrote three Energy Stories as they progressed through the units and revised their stories based on feedback from teachers. Energy Stories captured the details of students' understanding about the role of energy in the ecosystem and revealed how they built on their prior knowledge. Many students started with non-normative ideas about energy but became able to synthesize normative energy ideas, such as how light energy is transformed and how chemical energy is transferred, and use those ideas to restructure their initial understanding of energy flow in life science (see Table 1 for one example of a progression of student Energy Stories).

Energy Stories provided students with opportunities to reflect on the ideas they had investigated in two WISE units and to articulate them in their own words, which increased the coherence of their scientific explanations and deepened their understanding of how energy flows in life science. Energy Stories also helped teachers better understand how students were developing an integrated understanding of complex scientific concepts and linking energy ideas across the two units. One of the seventh-grade science teachers was amazed by the value of Energy Stories as both a learning activity and an assessment tool, saying, "It's a summary of what has happened, and they're writing it in their own words. . . it just encapsulates everything that had happened."

These findings underscore the value of blogs in providing recurring opportunities for students to iteratively integrate, reconsider, and refine their ideas about complex scientific phenomena. For teachers, this type of reflective writing provides opportunities to assess students' progress and provide timely feedback, which can strengthen instruction. Blogs can thus be an effective means of enacting such practices in the classroom.

Blogs for Learning, Table 1 Sample Energy Stories from a seventh-grade student across two WISE units

Initial Energy Story	The energy comes from the sun which goes into the chloroplast of the plant cells. There the energy gets transformed into plant food
Revised Energy Story	Once upon a time there was a plant. The plant had a job of making food for his rabbit. To make energy-rich food for the rabbit, the plant's chloroplasts collected water, light energy and CO2 for the food which is called glucose. Glucose is a type of sugar used to help plants stay alive and grow. In the plant's chloroplast, the light energy breaks apart the little water and CO2 atoms. When the light energy broke apart the atoms, it turned into chemical energy which decided to go inside the glucose and help give nutrients to the rabbit and the plant. The glucose traveled around the body and the extra ones were stored in the roots and leaves. When the rabbit ate the plant, the plant gave away some of the glucose. Even though it was very complicated to make glucose, the plant was happy to be generous
Final Energy Story	Once upon a time, there was a plant. The plant fed a rabbit named bobby. Bobby ate the plant's nutritious leaves full of glucose. The plant woke up every morning just before dawn. To make glucose, the plant needs sunlight, water, and CO2. The plant collected sunlight and CO2 with his leaves. His roots soaked up the water. All the CO2, water, and sunlight gathered up at the chloroplast where the water and CO2 atoms were broken apart and the sunlight was changed into chemical energy. The atoms were assembled into glucose molecules and the chemical energy was stored in the glucose. The left over atoms were made into oxygen. The glucose was stored in the leaves and roots for later use. Then Bobby came along and ate a leaf from the plant. The leaf went into Bobby's stomach and his stomach cells extracted the glucose from the leaf. The glucose went into the mitochondria with oxygen and the glucose and oxygen were broken apart into smaller pieces (atoms). The chemical energy was taken away from the glucose and the atoms of the glucose and oxygen molecules assemble themselves into CO2 and water molecules

Cross-References

- ▶ Computers as Learning Partners: Knowledge Integration
- ▶ Digital Resources for Science Education
- ▶ Online Inquiry Environments
- ▶ Technology for Science Education: Research
- ▶ Wikis

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Borders/Border Crossing

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Border crossing provides a lens for analyzing science learning as cultural acquisition and science teaching as cultural transmission. Thus, science is deemed as culture rather than absolute truth. The generic construction of border crossing assumes the existence of borders between two (or more) distinguishable cultures/subcultures that, to a varying degree, represent obstacles for individuals to cross. The notion of border crossing has been used widely in science education research to conceptualize difficulties that students encounter in science education. In research, science classroom experiences of students and teachers have been theorized in terms of the ease with which students and teachers cross cultural borders of the science classroom. Border crossings have been categorized as *smooth*, *manageable*, *hazardous*, or *virtually impossible* (Cobern & Aikenhead, 1998). The concept of border crossing was borrowed from cultural anthropology and first applied to Western students studying science by Aikenhead (1996) with an expressed aim to encourage science educators to acknowledge inherent border crossings between students' lifeworld subcultures and the subculture of science. The theoretical framework of cultural borders and border crossing have later been challenged for assuming subcultures as given entities and not fully taking hybridity, heterogeneity, and the situatedness of cultural practices into account (Carter, 2008).

Cross-Reference

- ▶ Acculturation
- ▶ Culture and Science Learning

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Botanic Gardens

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Botanical gardens are collections of well-documented and maintained living plants. While best known for aesthetic displays and tranquil settings, botanical gardens are key scientific research and conservation institutions as well as rich environments for learning.

The Purposes and Value of Botanical Gardens

The International Association of Botanic Gardens estimates that there are just under 1,800 botanical gardens in approximately 150 countries worldwide. Collectively, they serve approximately 150 million visitors a year. Botanical gardens generally aim to promote (1) scientific research, (2) conservation, (3) education, and (4) leisure experiences.

Learning in Botanical Gardens

Learning is a diverse endeavor. It encompasses a wide range of experiences, such as content acquisition, excitement and motivation, skill development, reflecting on the process of science, contributing to the generation of scientific knowledge, and identifying oneself as a scientist or science learner.

As places for learning, botanical gardens are designed to evoke emotion and reflection, prompt questions and exploration, and provide guidance and information. They actively seek to repair people's relationship with nature (sometimes referred to as "nature deficit disorder" (Louv (2005)), as well as people's lack of recognition that plants form part of the foundation of human culture and society by providing food, medicine, fiber, and building materials (referred to as "plant blindness" (Wandersee and Schussler 1999)). Learning experiences across botanical gardens vary, because they leverage the specific mission and resources of each botanical garden in order to meet the needs of their communities.

Botanical gardens' most prominent educational (and leisure) resources are their outdoor gardens and greenhouses (glasshouses) that focus on plant and garden displays. Common plant and garden displays include native plants; specialty plant groups like cacti; cultural gardens;

home gardens with flowers, edible plants, and sustainable living components; immersive environments that seek to replicate specific ecosystems like cloud forests; children's gardens; and scientific gardens that highlight biodiversity and evolutionary relationships among plants. In addition, botanical gardens often incorporate art and historic buildings as part of their displays.

Most botanical gardens offer educational programming. Four examples illustrate the range and diversity of learning opportunities offered. First, some botanical gardens train volunteer master gardeners and "plant doctors," who provide identification services and advice to visitors, in-person, online, or on the phone.

Other institutions have community gardens tended by local residents. In some programs, recent immigrants or rural transplants grow plants that represent their culture or life experiences. Using their harvests, participants share culinary and cultural practices. This facilitates community understanding as well as intergenerational dialogue within families. Such programs may also be combined with literacy opportunities for participants.

Common across botanical gardens are professional development offerings for K-12 teachers. Since the early 1990s, these classes have focused on teaching inquiry-based pedagogy and lending hands-on kits for classroom and community use. The classes and kits align closely with local, state, and national curricula in science, technology, engineering, and mathematics (STEM), as well as art and literacy standards.

Finally, many botanical gardens host festivals. Whether focused on green living and energy conservation, the sculpture of a country or an artist, seasonal changes, or religious observances, these festivals bring communities together and enrich the lives of visitors and increase their understandings of the natural world and human cultures.

Scientific Research, Conservation, and Learning at Botanical Gardens

Though few outside the botanical community get "behind the scenes," many botanical gardens are major research institutions, focusing on plant biodiversity, evolution, conservation, and sustainability. Documenting, studying, and preserving plant life and ecosystems are consistent with the history and commitment of botanical gardens. Some of the major botanical gardens in the world were founded in order to grow the strange, beautiful, medicinal, or economically important plants collected during times of exploration. Today, scientists at gardens are in a race against time to collect and study plants before they disappear due to urbanization, suburbanization, and agriculture. Approximately 80,000 of the 270,000 known species of plants are in cultivation in botanical gardens, including those that are threatened or endangered.

Scientific research, conservation, and learning at botanical gardens are often integrally connected. Programs at botanical gardens may include lectures or workshops on current scientific research and conservation efforts, tours of research labs or herbaria (collections of dried plant specimens; herbarium, singular) and conservation areas, or volunteer opportunities to work with research and conservation staff. In addition, some botanical gardens offer classes and degree programs at the university level. In addition, learning research also occurs at botanical gardens (see, e.g., Eberbach and Crowley 2009).

Challenges for Learning in Botanical Gardens

There are at least three major challenges for botanical gardens in achieving their educational aims. First, as enthusiasts and professionals alike report, becoming a gardener, a scientist, or someone knowledgeable about plants and the environment entails getting directly involved with one's subject matter. Whether crushing leaves to identify a plant by smell, collecting seeds for spring planting or conservation efforts, or using blossoms to create art, hands-on experiences are critical for learning. These authentic experiences are a resource challenge for botanical gardens. For example, for a garden to provide digging, planting, and harvesting opportunities for visitors, it must make a significant commitment in terms of staff, greenhouse space, and other resources to maintain a continuous supply of plant materials and supervised experiences.

Second, by striving to reach multiple and varied audiences, botanical gardens experience ongoing tensions between achieving a well-tended garden with a tranquil, idyllic atmosphere and creating a garden that is welcoming to people of all ages and interests. This tension plays out in terms of what learning experiences are offered, when, and to whom (Sanders 2007).

Third, time is needed for learning in botanical gardens. It is needed in two ways: time for nature and time for people. For example, time is necessary for plants to grow, for experiments to take place, and for seasons to change. In addition, time is needed for people to experience and enjoy the breadth and intricacies of botanical gardens and their offerings. In order to address both these issues, botanical gardens often promote memberships and events, provide classes in extended series, and encourage repeat visitation throughout the year and over years to foster greater understanding of the natural world and human cultures.

Summary

Botanical gardens are institutions that are deeply committed to and actively engaged in providing visitors with meaningful learning experiences, focused on the themes of biodiversity, evolution, conservation, and sustainability. The displays and programs botanical gardens offer are designed to appeal across age and interest groups and to address the full spectrum of what it means to learn.

Links to Some Significant Botanical Gardens

Kirstenbosch National Botanical Garden, South Africa http://www.sanbi.org/gardens/kirstenbosch/
Missouri Botanical Garden, US http://www.missouribotanicalgarden.org/
The Eden Project, UK www.edenproject.com/
New York Botanical Garden, US www.nybg.org

Cross-References

- ▶ Aquaria
- ▶ Excursions
- ▶ Interpretive Centers
- ▶ Learning Science in Informal Contexts
- ▶ Lifelong Learning
- ▶ Out-of-School Science
- ▶ Zoological Gardens

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Broadcast Media

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Broadcasting is primarily about dissemination. One source distributes to many potential recipients, who, if they are aware of the broadcast at all, can choose to engage or ignore. It is essentially a one-way communication process although technological advances are increasingly adding forms of interactivity and audience involvement. The principal broadcasting media are sound and vision, initially distributed in real time using signals transmitted through the air, but now accessible through a wide range of other distribution channels. The advent of recording media, and later on download on demand via the Internet, removed the need to make "an appointment to view," but listening and viewing scheduled transmissions is still the main way in which people access broadcast media.

Broadcast media contribute to science education in a variety of different ways. The BBC in the UK was founded with a commitment to public service broadcasting that aimed to contribute to cultural life. The first director general, John (later Lord) Reith, formulated the purpose of the BBC as to "educate, inform and entertain." The annual broadcast lectures that now bear his name have, since 1948, allowed some of the leading scientists who are also great science communicators to bring science to a wide, and international, radio audience. Although the lectures provide an immediate experience for the listener at the time of transmission, the archived lectures provide a continuing resource for education, both formal and self. These lectures can prove powerful calls to action. For example, the 1969 lectures by the ecologist Frank Fraser Darling are a major milestone, because from a position of great authority, he articulated an early warning of global warming.

Science broadcasting in Germany started in 1923, and by 1925 one regional radio station broadcast a science lecture every Monday at 7:30 p.m. Across the radio stations the quantity of science programming was high, and science was generally broadcast during prime time, not so much because it was popular then among the listeners, but more because it matched the educational and cultural philosophy of the state. Deutsche Welle (1926–1932) was a national educational radio station with science programs that were aimed at a general audience. There were also programs aimed at a learning audience and those wishing vocational training. The regional stations did not reduce their science contact, so science enthusiasts had choice. Additional supporting material was provided for some programs through a magazine, so the idea of the use of multiple media in educational broadcasting is quite an old one (Schirrmacher 2012). The present Deutsche Welle is a German international broadcaster and is unrelated to the earlier radio station.

The lecture is a traditional form of communication that transfers well to radio, but developments in television have produced two strong new strands of science education and involvement. Firstly, there is the involvement of viewers in scientific events, in the past the moon landings and in more recent times the search for the Higgs boson. Here, broadcast media clearly have a role in communicating science by explanation, but there is also the immersion of the audience in the atmosphere and excitement of the event itself. For almost 50 years postwar, this strand of science education represented a unique selling point for terrestrial and satellite broadcasters. Now, the Internet has provided new channels which can provide the experience and often enhance it. CERN, the European Organization for Nuclear Research, has a channel CERN News that provides regular programs about the physics experiments conducted at the laboratories. NASA TV has live coverage of its space research, viewable on computers and mobile devices.

The second strong strand that developed in television, particularly in the UK, was direct broadcasting to specific groups. School radio was established early on, and by 1930 there were already science broadcasts for schools, with programs designed to be included within the planned lessons during the day. Schools broadcasts on science on television followed in the 1950s, again being used within the school timetable. In 1971, the Open University started to broadcast programs directly related to individual undergraduate degree courses. Television and radio became the medium for the distribution of learning to students, and the programs were much more than lectures, encompassing in due course some very innovative science programming. The Open University of Japan broadcasts lectures in a traditional format to its students nationwide. The key point about all these developments is that while they are targeted at particular audiences, the "drop-in" audience can be highly significant. An Open University program between 1971 and 2000 might well have been aimed at a course of 400 students, but the drop-in audience would have been many times that figure, and, on at least one occasion, it reached one million for a single program. It is difficult to measure the educational effectiveness for the drop-in audiences, although there are a number of students who give broadcasting as their reason for applying for courses.

As technology has developed, so has the broadcast model. A science broadcast now may be part of a complete package focused around a "call to action." The call might be for audience participation in a specific activity or a more general call to do something positive, for example, volunteering for conservation projects. The package, supported by web pages, might also include a free print item that can be requested by telephone or online and road shows that provide the opportunity for some hands-on science. A recent innovation has been to associate a Twitter feed with a program and build the audience into a community who take the subject beyond what was actually broadcast. The ready availability of podcasts for download enables people to choose when to listen to a program and effectively increases the size of the audience. There have also been courses for credit linked to TV programs. The BBC's Natural History Unit (Gouyon 2011) produced a blue chip documentary series in 2011 called "Frozen Planet." It was presented by Sir David Attenborough, and the series had a free poster and a short, 10-week course of the same title, dealing with polar science. The packaging of many components around a broadcast, sometimes called 360° programming, has considerable potential for science educators to harness the power and reach of the broadcast media to bring science activities to a wide audience.

BBC Lab UK is a website where the public can take part in scientific experiments linked to broadcast programs. Scientists are invited to submit experiments that could benefit from mass participation. One of the most successful was the 2006 Sex ID experiment that formed part of the TV series "Secrets of the Sexes." Scientific papers based on the data collected were published in a complete edition of the journal *Archives of Sexual Behaviour*. There were 250,000 participants, a figure that demonstrates the power of the broadcast media to promote engagement with science.

There is plenty of potential for the broadcasting media to grow their role in science education, but analysis of factual science output suggests that the overall penetration of science into broadcast media is poor (Table 1). A study of the share of science programs on the Flemish Radio and TV network VRT showed that between 1997 and 2002 it varied between 2.97 % and 5.23 % (Maeseele and Desmet, 2009).

Broadcast Media, Table 1 Science broadcasting on terrestrial free-to-view channels in the UK for 1 week (October 2005)

Available broadcast hours on channels with a minimum of 1 program on science in the week (10 in all)	1,022 h
Broadcast hours devoted to science	29 h including repeats
Percentage of available time	2.9 %
Categories included	Science, earth science, nature, forensics, health, scientific archaeology, science history, and science medicine

The image of scientists as projected by radio, and more particularly television and film, is often negative and in drama sometimes far removed from reality. Male scientists tend to be represented as the norm and female scientists as exceptional. *MythBusters* from the Discovery Channel is a program that explicitly sets out to depict the culture of science and engineering in as accurate a way as possible, with the aim of remedying the lack of understanding of the subject areas among high school students and encouraging more to take them on. The series also tries to show people in the fields of science and engineering as realistically as possible (Zarvel 2011). The representation of science and scientists by the broadcasting media is an area of continuing debate, with the impression among scientists that they and their subject are underrepresented in broadcasting. Such figures as there are seem to bear this out. In 2012 the BBC appointed its first science editor, a welcome move, but editors for other subject areas have existed for many years.

There are tensions between, on the one hand, engaging the attention of the audience and retaining it through a program and, on the other, showing authentic and accurate scientific knowledge. This can be a very fine line, as the *MythBusters* series in the US and the *Bang Goes the Theory* series in the UK demonstrate. In each, audience excitement and scientific accuracy go hand in hand, but it is a difficult relationship to maintain. There are also tensions visible in programs about extinct animals where CGI (computer-generated imagery) techniques bring extinct animals alive on the screen. *Walking with Dinosaurs* was produced as if it was a natural history series, and although it had input from many scientists, particularly concerning biomechanics, it was criticized for including behavior, such as "bonding for life" for which there is no scientific basis (Campbell 2009). When fact and guesswork are mixed, without signposting, the science educator becomes uneasy.

The power of broadcast TV to disseminate science has been covered by a number of authors (e.g., the book by Willems and Göpfert 2006). However, there is an element of broadcast TV that is less well studied, and that is the commercial breaks between programs, which also contain science content. A study carried out in 1999 found that 65 % of all advertisements over a 2-week period marketed science-based products. It has been suggested that advertisements could be used to learn about science and, by examining them in detail, demonstrate the need for objectivity.

So for the future, science educators increasingly will be using the broadcast media as a source of material for learning, as a way of educating the general audience about science and its place in society, and for demolishing the negative stereotypes of scientists.

Cross-References

- ▶ Citizen Science
- ▶ Online Media
- ▶ Radio
- ▶ Television

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Café Scientifique

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Cafés scientifiques (also known as science cafés, particularly in the USA) are informal, accessible, gatherings in which members of the public and scientists meet to talk about issues in science and technology that affect people's everyday lives.

Café scientifique has its roots in the *Café Philosophique* movement, begun in France by the philosopher Marc Sautet. Café scientifique began almost simultaneously in France (1997) and the UK (1998); the network has gradually spread until now 2012, there are cafés on every continent, although the distributed nature of the café network makes it difficult to be precise about exactly how many there are at any time.

Café scientifique is a philosophy, rather than an organization. The café scientifique website and other country-based sites offer support, guidance, and mentoring to café organizers, but all cafés are organized locally and autonomously, with no one person or group in overall control of the network. This means that the format of cafés varies from town to town and country to country; this entry focuses on the "classic," British café scientifique model.

The defining feature of a café scientifique is the venue. Cafés take place in bars, cafés, pubs, art galleries, village halls, bookshops, restaurants, and similar generic venues, not in universities or lecture theaters. This removal of the location from the academic milieu to the community context is important on two counts. First, the nature of the venue shapes the nature of the discourse. The atmosphere of cafés is relaxed, informal, and egalitarian; in a café, we expect to have a conversation. In a lecture hall, we expect to be lectured at. Therefore, in a café scientifique, the emphasis is on dialogue among equals, not on the one-way transmission and reception of information. Second, the seating of participants around tables ensures that they engage as much with each other as with the speaker, tipping the balance of power toward the audience, rather than the speaker.

Cafés are cheap, simple, and people-focused. Most operate without any kind of formal funding. This is made possible by the peer-to-peer, informal nature of the movement. Café organizers are normally volunteers; the venues are often free or very low cost, as cafés fill the venue on otherwise quiet nights. Entrance is likewise free, although many cafés ask participants to make a donation toward the speaker's expenses. Speakers are often drawn from local industry or universities, so expenses are kept fairly low. Most cafés eschew the use of technology such as presentation software or microphones, in line with the philosophy of keeping the interaction between audience and speaker as egalitarian and balanced as possible.

The classic format for a café scientifique is that the speaker gives a short introduction to

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the topic, usually about 15–20 minutes. This is followed by a break, of around 20 minutes, to allow glasses to be refilled and conversations to start. Then there is an open discussion in which comments, questions, thoughts, and opinions are exchanged, as often among the audience themselves as between the audience and the speaker. Cafés usually have a “host,” or facilitator, whose role is to keep the discussion moving. The length of the discussion time varies from café to café but is typically around 45 minutes to an hour. Most commonly, cafés meet once a month, sometimes with a break in the summer.

This simple model is highly adaptable to different cultures. For example in continental Europe, cafés often have two to four speakers; this is seen as a way to maintain a balanced argument. In Japan, discussion points are sometimes submitted by SMS, to avoid the disrespect of directly questioning an elder or superior. The model has, with varying success, also been used in schools in the UK, the USA, France, and Uganda (see www.juniorcafesci.org.uk).

The beginnings of café scientifique coincided with the cultural change from the promotion of “public understanding of science” to “public engagement with science.” Cafés scientifiques perfectly caught the mood for direct and open public dialogue, in which scientists recognized the importance not only of talking to people about their work but also of listening to people’s views. This change also found favor with governments, as they sought innovative ways to sustain public discussion about issues in current science and technology. This cultural acceptance has meant that what started out as an avant-garde, independent, and bottom-up movement has become a widely accepted model for public engagement with science, embraced by the science communication establishment: research funders, governments, researchers, policy-makers, learned societies, and more. While many of these groups operate very effective cafés, there is a danger that their needs and agendas may override the basic principles of conversation, democracy, equality, and accessibility espoused by café scientifique.

Cross-References

- ▶ Learning Science in Informal Contexts
- ▶ Public Communication of Science and Technology
- ▶ Public Engagement in Science

Careers and Gender

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Across science fields, women have been and continue to be underrepresented. Some disciplines are approaching parity, such as biology, while others, such as chemistry and physics, still lag behind. The issue of representation is a complex and multifaceted one and, even with years of research, is not something that can be easily fixed. Many issues are culturally embedded and very difficult to address, including implicit bias and gender roles. Other issues are a result of the historical progression of women into the sciences. For hundreds of years, women weren’t allowed to be scientists. By the early twentieth century, several exceptional female scientists were making contributions to various fields, but the norm was for women to stay out of science. In the United States, the passage of Title IX ushered in a new era for women’s educational attainment. These early generations of women scientists fought for opportunities and to be treated equally. The current generation of women entering science has more options available to them and as a result makes active and complex decisions, which often lead them out of academic scientific research.

At a national level in the United States, there has been a recognized need to promote gender equality in science careers. Starting in the 1980s, the National Science Foundation developed programs to help female faculty become more successful researchers. The current incarnation of these is the ADVANCE program, which funds research on female faculty, research on gender issues within institutions, and transformative programs to support female faculty at individual institutions.

The University of Wisconsin and the University of Michigan were in the first cohort of institutions to receive ADVANCE funding. Both institutions implemented workshops to train faculty and search committees on subconscious or implicit bias. Using empirical data, these workshops were effective in increasing the number of women interviewed and hired for STEM faculty positions. This highlighted one of the challenges facing women's progress in science – the bias they faced anytime they were evaluated on their work or qualifications.

The culture of scientific research was founded on the male scientist working long hours and being devoted to research, while his wife supported him and was a homemaker. Indeed, American pop culture has supported the male "breadwinner" and the female "homemaker" as the ideal family for quite some time. These images strongly conflict with a female scientist pursuing a career and cause considerable gender role tension for many women and dual-career couples. Females still feel pressure to be the primary caretaker for children and elderly parents, regardless of their employment status outside the home. There is a prevailing perception that scientists should be devoted to their research, putting in long hours and working constantly, in order to be successful. Managing these two roles, as female and as scientist, causes struggles for many women in science.

One solution to this conflict is to pursue a scientific career at the expense of family. While this was often the case for early generations of women scientists, current generations are not willing to make that sacrifice. Associated with lifestyle issues is the cost or stress that can be associated with pursuing a career in scientific research. Women perceive that there is a lot to give up when pursuing a scientific career, including family and personal time. Additionally, there is often a lot of pressure to publish and secure grant funding, leading to a competitive and high-stakes environment. These factors often mean choosing careers outside of academic research, which they believe will allow them to balance their personal lives and careers.

Another challenge is the perceived lack of value in certain disciplines of scientific research. Many women report wanting to make a difference in the world through their careers, also known as career altruism. For some research, particularly in the physical sciences, the outcomes of research are very far removed from daily life. It can be challenging for women to feel they are spending their time on something worthwhile if they cannot see the value of research. For this reason, teaching and industrial careers often seem more appealing because they are perceived to have more tangible and immediate impacts.

Women tend to have a lower expectation of success in science than men, which may be partly due to bias or socialization. Most people do not choose to pursue careers they expect to fail at, so expectation of success is a necessary component in someone's decision to pursue a scientific career. Having multiple successful experiences, a supportive network, and an enjoyment of the work lead to a greater expectation of success.

With few women in scientific careers, a lack of role models can be a problem for women and girls looking to enter science. Additionally, students report that women faculty often are negative role models, embodying examples of women they do not want to be. Challenging these negative role models requires women to enter scientific careers despite the lack of positive role models, which can seem risky.

When making career decisions, it is common to construct multiple possible selves that are associated with different career options. These possible selves are then compared to a person's ideal self or the life envisioned in a perfect world. The career chosen typically is the possible self that is most like the ideal self.

One challenge for students making career decisions is a lack of knowledge about available careers. There is often partial knowledge or misinformation that is used to make career decisions. With the information available, though, women go through a complex decision-making process when choosing a career. Often, this process leads them away from scientific research for any number of reasons discussed previously, which further serves to reproduce the culture of scientific research that they are resisting and trying to avoid.

Cross-References

- ▶ Attitudes, Gender-Related
- ▶ Gender
- ▶ Socio-Cultural Perspectives and Characteristics

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Causal Reasoning

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Keywords

Causal induction; Understanding causality

Causal reasoning is a broad term used to refer to thinking that depends upon or aims to uncover a causal relationship between entities, events, or processes. It moves beyond the process of discerning patterns or covariation by looking for mechanisms that explain why two or more entities are related. Science often describes patterns – that something is connected, relates, or covaries with something else. It also seeks to define the reasons why particular patterns exist and this invites reasoning about mechanism – a key aspect of causal explanation. Human beings are sense-makers from an early age. Understanding the regularities in our world and knowing what accounts for them enable prediction and afford a sense of psychological control. An understanding of causality and its differences from correlation is therefore a central matter for science education.

When reference is made to causal reasoning, people often think about the ability to reason in particular ways. However, engaging in causal reasoning also involves perceiving or being sensitive to the occasion to engage in causal reasoning as well as being inclined to do so. This conception draws upon the triadic notion of thinking dispositions put forth by Perkins, Tishman, and colleagues. The research on what people do when cued to the existence of a causal pattern and asked to reason about it in contrast to how people engage in causal reasoning in everyday contexts is a key tension in research on causal reasoning as the paragraphs that follow elaborate.

Causal Mechanisms

Causal mechanisms refer to what makes the causal relationship happen. Mechanisms come in many forms. They may be physical as in mechanical devices, social as in intentions and goals, and biological as in germs and bacteria. Mechanisms can be described at different levels. For instance, one might explain why something happens by reference to a mechanical device or, at a finer level of grain, by reference to the forces involved. Consider causal explanations for what makes current in a simple circuit flow. One could respond at a number of levels, including flipping the light switch; opening a circuit and allowing current to flow; voltage that creates a push from the battery that moves electrons along a circuit; or a differential between electrons and protons at the poles of the battery that repels and attracts electrons so they move. Science often allows for more than one scientifically accepted mechanism. For instance, sinking and floating may be alternatively described with buoyancy or density explanations.

Causal Patterns

Causal patterns describe the covariation relationships and direction(s) of impact. When people think of cause and effect, they often think of a simple linear relationship involving a cause directly and immediately followed by an effect. However, causal relationships can be defined by a variety of patterns. For instance, there may be a bidirectional relationship between causes and effects as in mutual causality exemplified by symbiosis, commensalism, gravitational attraction, and so on. There may be a reentrant or cyclic causality involved as in relationships with inherent feedback loops, for instance, convection currents. Visualize the process involved in a home thermostat where convection currents trigger the thermostat to go on and off as the room cools and heats. When cyclic causal patterns have an amplifying feature, they can take on an escalating or spiraling pattern. Relational causal patterns involve a relationship between two variables, of equilibrium or of differential, that are responsible for an outcome. For instance, pressure differentials are responsible for air currents. Differentials in density account for the layers of our atmosphere – whether one layer sinks or floats on another.

Definitions of “pattern” and “mechanism” interact. For instance, if one believes that only the weight of an object is responsible for whether an object sinks or floats, they are likely to attribute a simple linear pattern. If one believes that a differential in density is responsible, then they are more likely to attribute a relational pattern.

Causal Features

Causal relationships are also characterized by features that can complexify the inherent causality. There can be time delays between causes and effects; causal action can be at a distance such that causes and effects are spatially separated. Causes can be obvious or nonobvious; for instance, carbon in the environment cannot be directly observed but its impact can, through adoption of specific causal reasoning based on extensive data. Other complicating features include tipping points or triggering features. These features result in departures from steady accumulation models and make it harder to detect when effects might occur. They tend to “hide” early accumulation because there is a certain amount of insurance in the causal system that accommodates early impacts. Therefore effects seem sudden and dramatic. Predicted climate change impacts are characterized in this way. Once a certain threshold is reached, a cascade of effects can dramatically occur. Reasoning about causality is impacted by these complexifying features because they affect the salience of the components in the causal equation and thus our ability to attend to them.

A significant body of research reveals that people operate via various default assumptions concerning the patterns, mechanisms, and features of causal interactions. A well-substantiated set includes a tendency toward assuming:

1. linear rather than nonlinear patterns
2. direct as compared to indirect impacts
3. unidirectional instead of bidirectional causal forces and impacts
4. sequentiality as opposed to simultaneity between causes and effects
5. that causes and effects will be obvious (until those possibilities have been exhausted) before considering nonobvious ones
6. that causes involve an actor and are intentional and active rather than non-intentional and passive
7. that causal investigation is warranted when a specific event occurs as opposed to recognizing that while events draw attention, they can be part of processes and steady states playing out over time that are inherent to a broader causal system
8. explicit notions of causality that are deterministic with one-to-one correspondences between causes and effects even if in our everyday reasoning (as discussed below) we

allow for causality based upon statistical regularities

9. that local causes and effects are local before considering distal ones
10. that the causal components are immediate to the outcome rather than time delayed or part of change over time
11. that causes are centralized with effects unfolding from that centralized cause in contrast to distributed or decentralized with emergent effects arising out of the many micro-interactions involved

These assumptions have a significant impact upon how we engage in causal reasoning. While these assumptions are driven largely from the modes of induction that we engage in (as discussed immediately below), attempts to make students aware of these patterns through higher-order reasoning and metacognition suggest some ability to moderate these expectations in situations that warrant it.

(Note: These default assumptions are elaborated and exemplified in Grotzer (2012).)

The cognitive science of how humans discern causal relationships

Three prevailing bodies of literature have made strong contributions to our understanding of how everyday causal reasoning works: Causal Bayes Nets (CBN) theories and the research on covariation that preceded it, specific generative transmission notions of mechanism, and the role of testimony from others (See Harris 2012).

CBN (Causal Bayes Nets) Approaches

CBN (Causal Bayes Nets) approaches are one of the prevailing model of how humans connect across statistical profitabilities to realize that a cause and effect are linked. Preceded by as rich research literature investigating how people attend to covariation between cause and effect, CBN theories argue that people sum across instances to discern causal patterns by association and that they also intervene upon and partition off certain variables to assess their impact. This, it is argued, allows people to detect causal structure by disambiguating causes. Intervention can refer to one's own actions, those of others, or those changes wrought by nature. A focus on covariation without attention to intervention or mechanism can lead to confusing correlative patterns for causal ones. Research by Alison Gopnik and her colleagues suggests that even young children follow Bayesian rules in summing across their experiences and that they are comfortable overriding imperfect correlation and using patterns of probability in contiguity to make causal inferences. Preschoolers were able to intervene to figure out the causal structure of problems with limited numbers of variables in deterministic and probabilistic contexts.

The existing studies on CBN reasoning were conducted in lab contexts without the attentional challenges and cognitive load of features that make "real-world" causality complex. Causal Bayes Net theories are effective in explaining how people meet with success in simple causal induction, but when causality becomes complex, issues arise. The CBN theory assumes acyclic patterns and the independence of the variables except for their direct and indirect effects (known as the Causal Markov Assumption). The real world is far more complex. One of the essential puzzles for CBN theories is to explain the ontological problem – how people get from a messy, complex world to a set of meaningful variables to reason about. Research on how initial, unconscious perception leads to attentional capture and then to focused perception shows that we miss a lot of information – especially when it does not fit with one's current expectations. So the question of how people know what to attend to from the wealth of stimulation coming their way poses challenges for applying a CBN model to a complex world.

For research purposes, CBN researchers often give the variables to the subjects. Further, intervening effectively in a complex world is a nearly impossible thing to do without sophisticated analysis. The unaided human mind in everyday contexts is unlikely to be able to effectively intervene and build effective causal models of such complexity. CBN accounts cannot fully enable complex causal reasoning. While much of the research on CBN reasoning is carried out in a lab in one attentional context, complex causal reasoning involves reasoning across spatial scales, extended time frames, instances where nonobvious variables compete for salience with more obvious ones, and complex patterns where effects may not become noticeable until substantive accumulation has occurred. If CBN reasoning is a predominant part of our causal repertoire, its shortfall may help to explain why people struggle so with causal complexity.

Reasoning About Mechanism

Reasoning about mechanism constitutes a second prevalent view in the cognitive science literature, represented by researchers such as Keil, Atran, and Leslie. It argues that people use their knowledge of mechanisms to reason about causality and that they amass considerable knowledge about types of causes, the causal force of particular mechanisms, and situation-specific details about where this information applies. For instance, consider how children learn about mechanisms such as remote controls, webcams, telephones, and so on, and then use this knowledge to reason about causality in particular instances. One strand of this research argues that what develops is a general notion of mechanism that children apply, but the other strand argues for domain-specific forces. Research supports the notion that children expect causal mechanisms and do not allow for causeless effects. Lacking knowledge of a causal mechanism, they may substitute magic as a mechanism – but they understand that explanation requires a mechanism. Further, even preschoolers reveal an understanding that mechanisms may not be obvious – as is the case with germs and contamination. Development appears to be in the direction of increasing knowledge of mechanisms and toward the realization that nonobvious mechanisms exist.

Testimony from Others

Testimony from others, a third body of research, focuses on how people learn from trusted others. Harris has argued that there are many concepts that children would never learn from firsthand experience alone and that the testimony of trusted others is an important source of learning about causal relationships. Complex causality offers many examples. For instance, the connection between automobile usage and changes to the polar bear habitats is unlikely to be discerned through covariation relationships and/or without deep and extensive knowledge of mechanisms that people would be unlikely to figure out on their own. Even the concept of sunburn – that a distant object in the sky can result in a painful burning sensation on one’s skin but over time and not necessarily when one is still in the sun but hours later – is most likely to be learned from others. Harris argues that testimony is an important avenue to learning about mechanisms that cannot be seen – germs, oxygen, and so forth. Testimony also comes in the form of powerful narratives. A well-known body of research by Daniel Kahneman and colleagues demonstrates that people have a tendency to override statistical data, such as that discussed above under the CBN approach.

Instead, in a tendency referred to as the availability heuristic, people use narratives in the form of powerful available cases to reason from. For instance, consider reasoning about food safety. A certain food may have been safe 100 % of the times a person has eaten it and may be deemed safe to eat by the scientific community. However, one highly visible or emotionally laden case where a trusted food turned out to be dangerous can change people’s consumption behaviors, at least for a period of time. This has happened in recent years with spinach, tomatoes, and cantaloupe, for instance. The cognitive load of summing across many cases may explain why we override this information with narratives motivated by affect; it may be adaptive to do so.

The research of Harris and colleagues demonstrates that even young children can be discerning about their informants and use subtle cues as to the reliability of the testimony that they hear. They attend to information about the informant: how much the informant is like them; how much consensus exists in the opinions of different informants; how familiar the informant is; and the perceived accuracy of the informant.

This suggests that variables in how causal information is communicated impacts how we incorporate and reason about that information.

In Conclusion

While these three modes of causal induction are often found in contrast to one another in the cognitive science literature, effective complex causal reasoning draws upon these forms of knowledge in ways that support and interact with one another. When cast in real-world contexts with messy, ill-structured problems, where sensitivity to causal instances, ability to reason in complex ways, and the inclination to do so are all in play, it makes sense that humans will bring their entire reasoning repertoire to bear on complex problems.

Cross-References

- ▶ Alternative Conceptions and P-Prims
- ▶ Argumentation
- ▶ Developmental Perspectives on Learning
- ▶ Epistemic Goals

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Chemistry

- ▶ Chemistry Teacher Education
- ▶ Chemistry, Philosophy of

Chemistry Teacher Education

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What Is Required of Chemistry Teacher Education

Certain key ideas appear to be necessary in any chemistry teacher education program. Gess-Newsome (1999), for example, highlights the need for integration of knowledge bases with informed decision making, exposure to examples of teaching excellence, and multiple supported experiences. These ideas are often in contradiction to preservice teachers' expectations as they expect to learn a "script" for chemistry teaching in line with their own successful learning experiences of chemistry in school. These ideas can also be in contradiction to chemistry teachers (and possibly the general public) who often believe that there is a received wisdom about learning to teach that can only be received by being in the classroom (an apprenticeship model).

How Is Chemistry Teacher Education Different from Studying Chemistry?

Studying chemistry is different from studying chemistry teacher education. Both chemistry and chemistry education are dependent on developing chemistry knowledge and their personal experiences, particularly in terms of how they know their chemistry knowledge. Chemistry teacher education also requires the development of knowledge in other domains such as pedagogical knowledge; subject-specific pedagogical knowledge (or pedagogical content knowledge (PCK) as defined by Shulman 1986); knowledge of educational contexts, purposes, and values (inclusive of curriculum, assessment, and evaluation); and knowledge of learners. It takes not only experience of teaching chemistry in schools if all of these knowledge bases are to be integrated, but also experience of other possibilities, feedback on different experiences, and time to make links between all of these factors.

Learning Progression: Big Ideas in Chemistry and How to Teach Them

One of the most cognitively demanding aspects of learning to teach chemistry is to identify the "big ideas" of chemistry which is followed by questions such as: what are age-appropriate views on these big ideas and if students do not hold the view, how does the teacher shift students' thinking in appropriate ways? For example, the idea of structure is one big idea, another would be chemical reactions. In looking at the idea of structure, the notion of particles is an early important idea, followed by progressively sophisticated ideas about what such particles might look like: a model for the particles (atoms). Understanding of the appropriateness of such a model rests in its ability to explain and predict most situations/phenomena, something that needs to be reached by the final years of secondary schooling. Understanding the progression of learning these ideas and that which is important and less important to learn also distinguishes chemistry education from chemistry and incorporates a small portion of the decision making that needs to occur when teaching chemistry.

Different Approaches

There are two dominant ways of viewing chemistry teacher education, with variations of each of these also apparent. These are chemistry teacher as learner and chemistry teacher as apprentice.

Chemistry Teacher as Learner

This approach concentrates on the development of pedagogical knowledge generally by paying attention to the learning experience (and its consequence then for teaching), with a clear focus on such understanding within a specific content area such as chemistry. Such an approach often requires the chemistry teacher educator and the preservice teachers to be co-learner and cocreators of knowledge (Corrigan 2009). Assessment tools need to focus on making judgments about the growth of the learners and identify what knowledge has been created in this approach. Reflection can often play an important role in assessment of this type with its ability to focus on a "problem" (a perplexing or curious situation) that can be framed and possibly reframed. In chemistry teacher as learner approaches, preservice teachers need to focus on their own "problems" rather than the problems of others.

Chemistry Teacher as Apprentice

This approach focuses on the development of pedagogical knowledge within the classroom, where continued experience promotes mastery of particular situations. However, if the apprenticeship occurs in a narrow range of situations, the ability to transfer what has been learnt to other settings is often hampered (Kennedy 1999). The integration of knowledge bases is often far less explicit, particularly if the range of experiences are limited. The focus remains on teaching rather than personal learning experiences, and so challenges to teaching styles can also be limited.

Chemistry Teacher as Clinical Expert

A variation on these models could be represented as *chemistry teacher as clinical expert* where there is a focus in the school component on developing particular expertise and competence in specified targeted areas. While this is more focused than the apprenticeship model, it is less reliant on reflection than the *teacher as learner* approach and therefore has differing consequences for understandings of being a teacher and doing teaching.

Cross-References

- ▶ Biology Teacher Education
- ▶ Curriculum in Teacher Education
- ▶ Pedagogical Content Knowledge in Teacher Education
- ▶ Pedagogy of Teacher Education
- ▶ Physics Teacher Education
- ▶ Science and Society in Teacher Education
- ▶ Science Teacher Education
- ▶ Secondary Science Teacher Education

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Chemistry, Philosophy of

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Keywords

Analysis; Chemical bond; Chemical element; Chemical equation; Classification; Disciplinarity; Inter-theoretic relations; Model; Periodic table; Reaction mechanism; Reduction; Representation; Substance; Synthesis

Philosophy of chemistry aims to provide robust analyses of the concepts, theories, and methods characteristic of chemistry and of the interrelations between them, including reflection on the ways in which they are related to, and potentially distinct from, the concepts, theories, and methods of other sciences. The following entry provides a brief survey of the main lines of investigation in contemporary philosophy of chemistry. More detailed treatments of these topics are found in Hendry et al. (2011), Van Brakel (2000), and Weisberg et al. (2011).

Core Concepts in Chemistry

Philosophy of chemistry, like the philosophical study of other particular sciences, devotes attention to the analysis of core concepts, including the concepts of chemical substance, chemical element, chemical bond, and reaction mechanism.

Chemical substances are the fundamental kinds of chemistry and are as important to understanding chemistry as the species concept is to understanding the biological sciences. There are three long-standing questions about substances: (i) What makes something a sample of the chemical substance that it is? (ii) What kinds of change can an exemplification of that substance survive? (iii) What is the difference between pure compound substances and mixtures? There are two general strategies for tackling these issues. One appeals to the molecular constituents of a substance and the other appeals to macroscopic criteria.

In either case, the theoretical building block for making sense of substances is the concept of the *chemical element*. Because it underwrites all chemical classification (discussed more below), an adequate analysis of the concept of element is necessary for an adequate account of substance. For individuating substances composed of a single element, the molecular strategy seems sufficient because the chemical properties of these substances are largely determined by the nuclear charge on the constituent atoms (i.e., the "atomic number" of the element). But compound substances are less amenable to a parallel treatment. Different substances may share the same elemental composition (in the case of isomers), elemental composition alone cannot distinguish between compounds and mixtures (e.g., hydrogen chloride gas and a mixture of hydrogen and chlorine gases in the corresponding proportions), and many compounds are simply not homogeneous at the molecular level. The most famous example is water: Pure liquid water consists of complex congeries of different species like H_3O^+, OH^-, and hydrogen-bonded oligomolecular structures, rather than collections of H_2O molecules, and this molecular heterogeneity is responsible for water's characteristic properties. If the relationship between molecules and substances is this complex, some have argued, the notion of "substance" may need to be understood independently of molecular constitution.

In fact, simple macroscopic criteria can clarify some of these cases. For example, a compound and a mixture of the same elements in the same molar proportions will exhibit radically different behavior under equivalent conditions of temperature and pressure. At room temperature and pressure, water is liquid but the mixture of hydrogen and oxygen is gas, and under conditions in which both are gaseous, the compound occupies two-thirds the volume of the same mass of the mixture. But the same thermodynamic grounding that captures our intuitions well in such cases would seem to view different isotopes of oxygen (^{16}O, ^{17}O, and ^{18}O) as different substances, because mixing samples of the different isotopes gives rise to measurable entropy changes. Yet chemical properties (i.e., dispositions to undergo chemical change), as mentioned earlier, are determined overwhelmingly by nuclear charge, which the different isotopes share, rather than atomic mass, with respect to which they differ.

Mixed substances pose a related set of problems concerning the persistence conditions of substance identity. When common salt (NaCl) dissolves in water, the ionic lattice breaks down, and the sodium and chloride ions form complexes with H_2O molecules. Is salt still present in brine? If not, what essential property of salt has been lost? On the other hand, if salt is said to be present, what should we say about a solution containing sodium hydroxide and potassium chloride? Is there salt here too? And how should we characterize the difference between pure and mixed substances in the first place? Potential answers drawing on either molecular or macroscopic criteria remain contentious, and the distinction between compounds and solutions itself comes under pressure with the recognition of nonstoichiometric compounds in the twentieth century.

After substance, perhaps the most central concept in modern chemistry is that of a *chemical bond*. The chemical bond serves to explain an extensive array of phenomena ranging from basic properties of bulk substances to whether particular reactions will occur under given circumstances, and what reaction pathways will be followed. In turn, the chemical bond is itself an object of explanation within the discipline. In contemporary practice the bond concept is a conceptual amalgam generated by the creative melding of classical and quantum notions following the incorporation of quantum mechanics into chemistry in the early twentieth century. At least two distinct conceptions of the chemical bond, the structural and the energetic, have been distinguished by philosophical analysis (Hendry et al. 2011). Each conception faces challenges with respect to internal consistency, coherence with physical theory, or explanatory completeness, and either would require significant development to provide an analysis both satisfying and sufficient. But can the chemical bond concept serve its explanatory role if it cannot be given a fully coherent interpretation within chemistry or if it is not fully consistent with more fundamental physical theory?

Another concept worthy of sustained attention is that of a *reaction mechanism*. To the extent that chemistry is the science of the transformation of substances, reaction mechanisms become a primary tool for explaining and predicting key facts about complex reactions: the nature of the various products, the quantities in which they are produced, and how these vary as the physical conditions change. William Goodwin has argued that organic chemistry actually employs two related mechanism concepts, the "thick" and the "thin" (Hendry et al. 2011). The thin conception is entrenched in practice, littering laboratory blackboards with diagrams and supporting the common reasoning patterns required to meet organic chemistry's particular predictive and explanatory aims. The thick conception, on the other hand, most readily connects mathematical models of chemical transformation to the experimental data measured in the laboratory. Further analysis of reaction mechanisms, especially as they relate to mechanism concepts in other sciences, remains a fruitful topic for future research.

Chemical Methods

In addition to conceptual analysis, many of the issues that demand philosophical attention concern the methods of chemistry, broadly construed.

Chemistry has an enduring concern with *classification* because of the multiplicity of distinct substances within its domain. Since the introduction of a compositional nomenclature in the 1780s, chemical classification has been erected principally upon a theory of constituents. The *periodic table* of elements is the most visible, and most fundamental, classificatory structure in chemistry. In its contemporary incarnation, the table serves to connect the realm of substances with the realm of atoms and molecules through the concept of *chemical element* (mentioned earlier). By highlighting the role of periodicity in chemical inference (roughly, analogical reasoning based on chemical similarity), the periodic table is a prime example of a representational tool that provides a framework for robust reasoning.

Indeed, the pragmatic significance of *representation* emerges as a general theme in recent philosophical work. The periodic table's two-dimensional matrix explicitly organizes elements in terms of horizontal and vertical relationships that facilitate identification of chemical similarity groups and trends. Similarly, because physical models effectively support reasoning involving spatial relations, such models flourished during the development of both nineteenth-century stereochemistry and twentieth-century macromolecular biology. Graphical formats support identification of potential energy surface maxima and minima that are crucial for determining reaction pathways. And the shift from largely intractable mathematical representations to diagrams was instrumental in allowing quantum-mechanical models of molecules to guide chemical reasoning regarding chemical bonding and reactivity. Perhaps most centrally, *chemical equations* function as an explicit bookkeeping device that relies on an inherent ambiguity regarding whether the equations represent facts at the level of substances or molecules. In each of these examples, the specific representational format is crucial for the efficacy of the inferential scaffolding.

More generally, investigations concerning the role, function, and significance of chemical *models* mirror those prominent throughout contemporary philosophy of science. As seen across the sciences, models in chemistry rely frequently on idealization and approximation for their power. We see this vividly in models ranging from the ideal gas law to mathematical models in quantum chemistry to ball and stick physical models in the classroom. Some models aim to provide explanation, others generate predictions, and still others facilitate and entrench common patterns of reasoning. Philosophical discussion of models as "mediators" between theory and phenomena is especially relevant to understanding this range of functionality.

Chemistry's laboratory practices are also distinctive, guided as they are by focus on the reliable manipulation and manufacture of substances. Control of this sort has been realized through the conjoined methods of *analysis*, by which chemists determine the constituents of a given substance, and *synthesis*, by which predetermined substances, or more minimally substances with desired properties, are produced. The basic questions are clear: How are synthesis projects conceptualized and organized? How are laboratory practices coordinated with theoretical representations? What are the characteristics of rational search for synthetic pathways? Innovations such as the development of automated search techniques raise interesting methodological questions, as does the heavy reliance on technological *instrumentation*, especially various forms of spectroscopy, for identification of chemical kinds. The epistemic challenges, as well as advantages, that accompany reliance on such instrumentation require systematic analysis.

At a more basic level, we might consider whether, and how, synthetic goals shape the very nature of chemistry as a science and ask how greater understanding of chemistry's orientation toward the controlled production of designed novelty clarifies or challenges traditional assumptions involving the relative disciplinary homogeneity of the physical sciences, the distinction between science and engineering or pure and applied science, and the role of values in science generally.

Relations Between Chemistry and Other Sciences

Intuitively, chemistry seems individuated by its characteristic concepts (substance, element, bond, etc.), but can these concepts be fully understood in terms of the concepts of physics? If not, can the chemical explanations that employ them be replaced by explanations that appeal only to physical concepts? Critically examining the assumption of reducibility is a theme that runs throughout contemporary philosophy of chemistry.

Any general framework should distinguish between *inter-theoretic* and *ontological reductions*. Traditionally, inter-theoretic reduction has been the central topic of debate. But even if chemical theories are irreducible to physical theories (inter-theoretic), the question remains whether the subject matter of chemistry is, in some sense, just that of physics (ontological). Recent arguments demonstrate that a robust conception of molecular structure cannot be recovered in a fully principled manner from the equations of nonrelativistic quantum mechanics (i.e., without making what is normally called the Born-Oppenheimer approximation). Molecular structure is effectively introduced ad hoc rather than explained. More generally, quantum chemistry appeals to concepts and traditions of representation from both physics and chemistry. This suggests a synthesis of chemistry and physics, rather than a reduction of one to the other. In a similar vein, the laws of thermodynamics provide constraints on chemical explanations without providing such explanations in full, again suggesting a non-reductionist model for the explanatory role of physical theories in chemistry.

Alongside these long-standing issues, *disciplinary differences* have emerged as a distinct philosophical concern and one that does not reduce to relations between theories. The historical development of molecular biology in relation to biochemistry reveals clear differences in the explanations offered within each subdiscipline, suggesting the disciplines may be meaningfully differentiated by their respective explanatory strategies. Meanwhile, consideration of prominent techniques for rational drug design, a landscape that places chemistry in close contact with pharmacy, suggests that we would do well to attend to the materiality and explicitly productive (medical, industrial, technological, and otherwise commercial) orientation of much chemical research. A broader issue concerns whether chemistry is currently fracturing from a unified discipline into a wide range of importantly distinct interdisciplinary enterprises such as molecular genetics, environmental science, and nanoscience. Examining interdisciplinary relations provides a different perspective on issues of reduction and autonomy, although they do not, by themselves, settle any traditional philosophical issues. More modestly, they highlight the social nature of theoretical, experimental, and technological achievements within chemistry.

Cross-References

- ▶ Biology, Philosophy of
- ▶ Epistemic Goals
- ▶ Mechanisms
- ▶ Models
- ▶ Representations in Science
- ▶ Scientific Visualizations
- ▶ Social Epistemology of Science
- ▶ Values in Science
- ▶ Visualization and the Learning of Science

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China (PRC)

▶ Science Education in Mainland China
▶ Science Teacher Education in Mainland China

Citizen Science

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Citizen science is a term most often employed to describe projects for which volunteers collect data for use in organized scientific research. This usage of the term emerged from the Cornell Lab of Ornithology in 1994 when the lab desired a new name for its rapidly growing assemblage of data collection projects focused on birds. At that time, volunteer data collection efforts were relatively few in number, and most of the ones that did exist focused on monitoring the quality of lakes, streams, and rivers. Twenty years later, data-driven citizen science projects number in the thousands, and their participants number in the many hundreds of thousands. Projects cover a breadth of topics ranging from native bees to invasive species, from urban birds to arctic glaciers, and from pollen to stardust. Some projects engage a handful of participants in one small watershed, while others enroll many thousands of observers dispersed across several continents. Although projects vary in the degree of collaboration between volunteer participants and science researchers, in most projects volunteers receive some degree of guidance in project procedures to ensure consistency in data collection and accuracy in data analysis. The scientific impact of these projects, which yield knowledge by collecting and analyzing vast quantities of data at unprecedented scales, is easily measured by the rapidly growing number of publications based on volunteer-collected data (listings of projects and published papers are available at www.citizenscience.org).

While citizen science is sometimes considered a recent phenomenon, amateur scientists have been studying the world for much of recorded history, usually by noting observations of the environment around them. Also known as "volunteer monitoring" and "community science," citizen science efforts have yielded important datasets, specimen collections, and scientific insights since the seventeenth century and probably before. Much of our current information about the distributions of plants and animals, the timing of events in nature such as plant budding and bird nesting, the quality of water in streams and rivers, and the impacts of climate change on organisms around the world is derived from data collected by members of the public.

Although citizen science as a concept has a long history, the strategy of involving the public in scientific research as a method for increasing public science literacy is relatively recent. In the late 1980s, a group of educators pondering innovations in science education realized that by providing participants in volunteer monitoring projects with materials to support learning – for example, information about why a project was started, what scientific questions it was investigating, how a participant's data would be combined with data from others to answer those questions, and details about the organisms or phenomena being studied – the participants might learn scientific facts and concepts and also begin to understand how scientists conduct investigations that yield evidence-based results. For example, for The Birdhouse Network – which began in 1995 and is now part of Project

NestWatch (www.nestwatch.org) – participants kept track of the birds nesting in birdhouses in their yards and communities. They noted the species, number of eggs laid, timing of hatching and fledging, and overall nesting success and then submitted their data to a centralized project database. The data were then analyzed by scientists to determine information such as the influence of latitude on nesting success. At the same time, through the process of learning about cavity-nesting birds and studying their breeding behavior – which was supported by instructional booklets, posters, and simple data forms – project participants increased their knowledge of a number of aspects of bird biology.

As the twentieth century got under way, the idea that public participation in organized research could yield "hands-on" science learning took hold rapidly, and the number of projects intended to achieve goals for increasing both science knowledge and public science literacy began to multiply. The expansion of complex citizen science projects was further fueled by the development of the Internet, which allowed project participants to submit data to online databases and, in some cases, to be able to access project data for their own interpretation. Also, some citizen science projects, such as the University of Minnesota's Monarch Larva Monitoring Project, began to develop science curricula specifically designed for K-12 teachers who wished to incorporate citizen science into their classroom activities. Such curricula have been shown to help students learn many different aspects of science such as content knowledge and understanding of key features of scientific investigations and the nature of scientific research.

In response to the burgeoning field, the US National Science Foundation funded a workshop in 2007 that assembled 50 citizen science project leaders to discuss "best practices" for citizen science project design. The workshop yielded the "Citizen Science Toolkit," which provided guidelines for developing, implementing, sustaining, and evaluating projects designed to achieve outcomes for both science and education. The NSF funded a second citizen science conference in 2011; this one focused on how citizen science projects could advance the field of biological conservation. The proceedings of these two conferences, both available at www.citizenscience.org, are a rich introduction into the field of citizen science and its outcomes for a wide range of project types. And in 2012, an open conference on citizen science held in Portland, Oregon, attracted nearly 300 professional scientists and educators who discussed a wide range of project models and who launched an International Association for Citizen Science (reports from this conference also are available at www.citizenscience.org).

In the early 2000s, a new form of data-driven citizen science began to emerge, born of developing technology and the concept of crowdsourcing. At the vanguard was a project called Galaxy Zoo, which employed the power of the Internet to enable members of the public to classify images of space captured by the Hubble Space Telescope. This form of citizen science became very popular as new projects were developed to explore the surface of the moon, model Earth's climate using historic ship logs, and explore the ocean floor (www.zooniverse.org). Like the earlier monitoring projects, many of these data classification projects were intended not only to achieve scientific goals but also to help participants learn scientific information and develop positive attitudes toward science while participating in the scientific process. For example, participants in a project called "Citizen Sky" have demonstrated a positive change in scientific attitudes, apparently related to their engagement in the project's social activities.

In 2009, a group of researchers working under the auspices of CAISE (Center for Advancement of Informal Science Education) produced a document that described different models of citizen science for which participants collect or classify data. These authors introduced the term "Public Participation in Scientific Research" (PPSR) as an umbrella concept to refer to a range of project types that engage participants in the scientific process to varying degrees. The authors found that different PPSR models yielded different types of learning outcomes and suggested that project developers be deliberate in their project designs, carefully matching design to desired outcomes.

An additional form of citizen science also exists as described by Alan Irwin in his 1995 book *Citizen Science: A Study of People, Expertise, and Sustainable Development*. In contrast to the definition of citizen science as the engagement of volunteers and professionals in collaborative research to generate new science-based knowledge, the concept of citizen science that Irwin champions aims to bring the public and science closer together, to consider possibilities for a more active "scientific citizenship," and to involve the public more deeply in issues related to risk and environmental threat. Some data-driven citizen science projects do have objectives for achieving better linkages between science and society and even "democratizing" science, such as work currently being conducted in Europe by the Extreme Citizen Science group (ExCiteS: http://www.ucl.ac.uk/silva/excites).

With its goal of transforming the world through the bottom-up creation of knowledge, the future of the citizen science field seems nearly boundless. The ultimate success of the field will be measured by the ability of citizen science to empower members of the public to invoke transformative change for themselves, society, and the environment, blending concepts and ideas from all forms of public participation into powerful societal change.

Cross-References

▶ Public Engagement in Science

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Classroom Learning Environments

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Keywords

Assessment; Environments; Learning

Students spend a huge amount of time at school – approximately 7,000 h by the end of elementary school, around 15,000 h by the completion of secondary school, and nearly 20,000 h by the completion of university. However, despite the obvious importance of what goes on in classrooms, most teachers and researchers rely heavily and sometimes exclusively on the assessment of academic achievement and other learning outcomes.

This entry is devoted to conceptualizing, assessing, and investigating what happens to students during their education by drawing on the field of classroom learning environments. Clearly, having positive classroom environments is a valuable goal of education. But, it should not be assumed that the equally important issue of student outcomes is ignored in this entry. Extensive past research provides consistent evidence that the classroom environment is so consistently associated with student outcomes that it should not be ignored by those wishing to improve the effectiveness of classrooms.

A milestone in the historical development of the field of learning environments occurred approximately 40 years ago when Herbert Walberg and Rudolf Moos began seminal independent programs of research that formed starting points of the work encompassed by this entry. Walberg developed the Learning Environment Inventory as part of the research and evaluation activities of Harvard Project Physics, whereas Moos developed social climate scales for various human environments, including the Classroom Environment Scale. Although learning environments research originated in the United States, it soon spread to other countries, especially Australia and the Netherlands. Furthermore, particularly in the last decade or so, Asian researchers have made comprehensive and distinctive contributions (Fraser 2012).

Assessing Learning Environments

Although classroom environment is a subtle concept, remarkable progress has been made in conceptualizing, assessing, and researching it. A considerable amount of work has been undertaken in many countries on developing methods for investigating how students and teachers perceive the environments in which they work. In particular, over the years, researchers have developed numerous questionnaires to assess students' perceptions of their classroom learning environments. For example, these questionnaires provide information about whether a class is dominated by the teacher or is student centered; whether students actively participate in class or sit and listen to the teacher; whether students cooperate and discuss with each other when they are learning, or whether they work alone; whether the teacher is supportive and approachable; whether the students have a say in the choice of teaching and assessment methods; and whether differences in students' interests and speeds of working are allowed for by the teacher. Some examples of popular classroom learning environment questionnaires, together with the dimensions that they assess, are given below:

- What Is Happening In this Class? (WIHIC) – student cohesiveness, teacher support, involvement, investigation, task orientation, cooperation, and equity
- Constructivist Learning Environment Survey (CLES) – personal relevance, uncertainty, critical voice, shared control, and student negotiation
- Science Laboratory Environment Inventory (SLEI) – student cohesiveness, open-endedness, integration, rule clarity, and material environment

These questionnaires have been used in different countries and at different grade levels. They have been translated into various languages, including Spanish, Arabic, Chinese, Korean, Indonesian, Thai, and the South African language of North Soto. They have been used by hundreds of researchers, thousands of teachers, and millions of students around the world. Most teachers and researchers find that it is easy and convenient to use these instruments to obtain information about learning environments from students.

Over the past four decades, learning environment researchers have attempted to answer many interesting questions. Does a classroom's environment affect student learning and attitudes? Can teachers conveniently assess the climates of their own classroom, and can they change these environments? Is there a difference between actual and preferred classroom environment, as perceived by students, and does this matter in terms of student outcomes? Do teachers and their students perceive the same classroom environments similarly? How does the classroom environment change when a new curriculum or teaching method is introduced? Do students of different abilities, sexes, or ethnic backgrounds perceive the same classroom differently? These questions represent the thrust of the work on classroom environment over the past 40 years (Fraser 2012).

Researchers have carried out many dozens of studies into the relationship between student outcomes and the quality of the classroom learning environment. These studies have been carried out in numerous countries and at various grade levels with tens of thousands of students. The consistent evidence from these studies is that the nature of the classroom environment is related to student outcomes (both cognitive and affective). Therefore, teachers should not feel that it is a waste of time for them to devote time and energy to improving their classroom environments because research shows that attention to the classroom environment is likely to pay off in terms of improving student outcomes.

Classroom environment instruments have been used as a valuable source of process criteria in the evaluation of educational innovations. For example, Martin-Dunlop and Fraser (2008) evaluated an innovative science course for prospective elementary teachers in a large urban university in California. When learning environment scales selected from the WIHIC and SLEI were administered to 525 females in 27 classes, very large differences were found on all scales (of over 1.5 standard deviations) between students' perceptions of the innovative course and their previous course.

Feedback information based on student perceptions has been employed in a five-step procedure as a basis for reflection upon, discussion of, and systematic attempts to improve classroom environments at various levels of education (Aldridge et al. 2012). First, students respond to the preferred form of a classroom environment instrument, with the actual form being administered in the same time slot about a week later (assessment). Second, the teacher is provided with feedback information derived from student responses in the form of profiles representing the class means of students' actual and preferred environment scores (feedback). These profiles permit identification of the changes in classroom environment needed to reduce major differences between the nature of the actual environment and that preferred by students. Third, the teacher engages in private reflection and informal discussion about the profiles in order to provide a basis for a decision about whether an attempt would be made to change the environment in terms of some of the dimensions (reflection and discussion). Fourth, the teacher introduces an intervention of approximately 2 months' duration in an attempt to change the classroom environment (intervention). Fifth, the students' actual form of the scales (i.e., the environment that the students perceive that they actually are experiencing) is readministered at the end of the intervention to see whether students are perceiving their classroom environments differently from before (reassessment). These studies usually reveal that there has been an improvement in classroom environment and that teachers value their involvement in this action research aimed at improving classroom environments (Fraser 2012).

Although this entry gives emphasis to assessing classroom environment questionnaires that tap students' perceptions, which has been the predominant method in past research, it is important to note that significant progress has been made in using quantitative and qualitative methods within the same study of classroom environments (Tobin and Fraser 1998). For example, in a multilevel study of the learning environment, qualitative methods involved visiting classes, using student diaries, and interviewing a teacher-researcher, students, school administrators, and parents. A video camera recorded activities, field notes were written during and soon after observation, and team meetings took place regularly. Based on this study, Tobin and Fraser (1998, p. 639) concluded: "We cannot envision why learning environment researchers would opt for either qualitative or quantitative data, and we advocate the use of both in an effort to obtain credible and authentic outcomes."

Conclusion

Several implications emerge from this entry for improving science education. First, because measures of learning outcomes alone cannot provide a complete picture of the educational process, assessments of learning environment should also be used to provide information about subtle but important aspects of classroom life. Second, the evaluation of innovations and new curricula should include classroom environment instruments to provide economical, valid, and reliable process measures of effectiveness. Third, teachers should use assessments of their students' perceptions of actual and preferred classroom environment to monitor and guide attempts to improve classrooms. Fourth, when assessing and investigating classroom environment, a combination of qualitative and quantitative methods should be used instead of either method alone.

Cross-References

- ► Evaluation
- ► Learning Environment Instruments
- ► Program Evaluation
- ► School Environments

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Classroom Organization

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Keywords

Classroom management; Discipline; Effective teaching; Instructional repertoire; Learning environment; School culture

Since 1970, the journal Phi Delta Kappan has reported Gallup Poll results on US public perceptions of schools. Amongst other things, the poll identifies the biggest problems facing public schools; in 2010 and 2011, lack of funding for schools was number one with discipline and classroom control being second. Discipline and control has been number one or two for the last 42 years. Why is the issue of "discipline" so persistent? My guess is that we fail (collectively) to grasp the complexity of the teaching and learning process and the ways that more effective teachers encourage appropriate behavior and how they respond to students who behave inappropriately. The conundrum with effective teachers (science teachers included) is that they are often so smooth and seamless that we don't notice what they do unless we are actually looking for it.

Teaching is one of the most complex, demanding, and important of all occupations. Teachers (on average) interact with 20–30 students for 180–200 days a year, for 6–8 hours a day, encouraging students to focus on approximately 400 learning outcomes per year; during that time, very little is predictable. Each day students of different cultures, races, and genders enter science classrooms. Those students bring by-default factors over which the teacher has little control (e.g., fetal alcohol syndrome, dyslexia, autism, deafness, blindness, parents divorcing, living in poverty, being gifted, witnessing violence, being abused at home either physically, emotionally, mentally, etc.). To increase the complexity still further, those factors get nested into the literature on multiple intelligence and learning styles.

Striving to balance students working alone, competitively, and cooperatively in a laboratory-oriented science educational setting creates an intense context that can often result in conflict. Conflict (like change, stress, and competition) is not inherently good or bad. What makes conflict "good" or "bad" is the stance we take towards conflict combined with the skill sets we invoke to restore social order so that learning can continue.

So, for example, a student may say, "This is boring!" The less effective science teacher is more likely to take this personally and respond in a way that "pushes back" with the consequence of bonding the student against the teacher. The "expanded problem" is that if that student has friends, those friends also bond against the teacher. The effective teacher is unlikely to get "caught" and might say, "Boring for you? Listen, I had to plan it last night PLUS I have to teach it today. You should be feeling sorry for me right now," or "You're right, this is boring; tomorrow I'll do a better job" (the Tai Chi response), or "Thanks for being brave enough to let me know," or "Boring today? Well, enjoy today because it is downhill the rest of the year." They use humor, wit, truth, and humility – the Tai Chi's of classroom management: they merge the heart and mind.

The key idea here is that if the rest of the class has bonded with the teacher, the teacher's response works; if not, the response is less likely to work. Over the years, I have found that the issue is not the specific response, but rather the respect the students have for the teacher. No matter how well prepared teachers are, all students, at some time, are going to behave inappropriately and teachers have to deal with it.

In this brief entry, I explore the complexity of designing and enacting a science learning environment as it relates to how teachers encourage appropriate behavior and how they respond to students who choose to behave in a way that makes it difficult for teachers to teach and students to learn. The ideas being shared are the result of having worked with teachers for almost 40 years: having worked with teachers who ranged from those at risk of losing their teaching credentials to teachers identified as the most effective. I start with a few "prevention" ideas to consider before I develop an introduction to a repertoire of ways to interact with student off-task behavior.

The prevention side involves the intersection of numerous factors. I briefly discuss five factors. Whenever one of these five areas is not enacted effectively, the teacher increases the chances students will behave inappropriately and decreases the chances of resolving the issue: (1) teacher personality, (2) teacher's knowledge of curriculum, (3) teacher's ability to assess student learning, (4) teacher's instructional repertoire, and (5) the school culture.

Teacher Personality

When we ask science teachers to reflect on their great teachers, what comes up is sense of humor, enthusiasm, caring, challenge, and politeness. When we ask the same teachers to think of teachers they did not respect, the answers are the opposite, boring, didn't want to be there, embarrassed you publically, etc. You can see that teacher personality is a key piece. Interestingly, teachers can easily remember how the less effective teachers responded to students who were off task; however, they struggle to remember the specific responses of effective teachers. Why? Because they were smooth, seamless, kind, and kept it low-key emotionally.

Curriculum

Students also talk about being challenged, being involved in engaging, meaningful science lessons. They enjoy teachers "who really know their stuff," who make connections between science and other aspects of life, help students make a quilt of ideas. Students are less likely to be off task in those classrooms; and when they are off task, the teacher simply reminds them to focus by enacting a glance, a name, a pause, a gesture, a cough, a please, a "shift" of proximity, or some combination, but done respectfully so as not to provoke an escalation. These skills augment, rather than override careful planning, particularly where practical science activities are concerned; teachers need to plan and sequence physical enactment and intellectual engagement of students with each learning activity.

Assessment

Feedback has one of the highest effects on student learning; how we choose to assess student learning, how we encourage them to give us feedback, and how we give them feedback are critical. Hattie's (2012) research identifies feedback as one of the most powerful ways to impact student learning. Successful science students are less likely to be off task. Of course, when it comes to assessing student learning, if we as teachers fail to first assess our instructional repertoire and its effectiveness, then any decisions we make about student learning are going to be suspect.

Instructional Repertoire

Current research (Leithwood et al. 2009; Hattie 2012; Fullan 2011) reports that the teacher's instructional repertoire and their ability to differentiate their instruction are key predictors of student success. That said, teachers will struggle with 'differentiating instruction' in the absence of an extensive instructional repertoire. Instruction is one part of how teachers respond to the different intelligences, learning preferences/roadblocks, etc. Although most science teachers reserve the revered lab experiment as the means by which instructional practice is intentionally altered. However, teachers who structure groups effectively, frame questions effectively, listen and respond to student interest, etc., in varied and interesting ways are going to have less classroom conflict.

School Culture

If the school culture is balkanized, with no norms of collegiality or collaboration, then the school is unlikely to have a clearly articulated (enacted) school-wide set of procedures for effectively encouraging appropriate behavior. The reverse would be the case for a more collaborative school culture. The front "office" is of little value if school administrators have no idea why the student ended up in the office and what the teacher did to prevent the student ending up in the office in the first place. And just as problematic, the science teacher who sent the student has no idea what will happen at the office once the student ends up in the office.

When considering those five factors, one senses that prevention is more complex than it looks. In terms of school culture, all staff members must work together to create and enact a system that responds to student unacceptable behavior and to make sure they are not the reason the student(s) behaved inappropriately.

In the next section I situate how teachers respond to students once students get "off task." (See *Power Plays*, Bennett and Smilanich 2012). As science teachers, we must consider that students may be off task because the lesson is boring, meaningless, or of no interest or the classroom is not a safe place to learn. If that is the case, the teacher is part of the problem. Metaphorically speaking, if a restaurant gave us poor service, unpalatable food, and an ambience not conducive to eating, we would not return, and we would inform our friends so that they could avoid it too. We all assess before, during, and after eating. Students do the same thing: they assess before, during, and after learning, and they inform their friends of their conclusions. The "teaching" problem is that the science classroom is the only "restaurant" in town. How would you behave if the restaurant you had to eat in 200 days a year had poor food, poor service, and a poor eating environment?

Our students, albeit tacitly, have "scored" us. If our customer service rating averages out at 75 % or higher, things will go relatively smoothly; we can rely on a smaller set of skills to respond to the students because the students have bonded with us instead of against us. If our service rating is less than 50 %, we are going to struggle in the science classroom. Science teachers with higher ratings tend to believe that no matter how well planned, prepared, kind, and thoughtful they are, all students, at some time are going to misbehave and that they have to deal with it. They are less likely to be disappointed and are less likely to take it (show it) personally. As a result, the more effective science teachers have a more extensive enacted repertoire – they show greater flexibility (are more artful) in how, where, and when they respond to students: they are much less likely to judge. They are also more likely to spend more time working to understand how to work with students rather than how to control them.

When we ask grade two or grade 12 students to tell us what their teacher uses to get them to refocus, the students will say things like "they look at us,” or “they say our name,” or “they come over and sort of take it away,” or “they just come close to us so we stop.” Those are not secret skills, parents use them as well. We call these “invisible discipline skills.” The problem is that having the skills is the science, enacting them is the art. I explain the “art” piece in the next paragraph.

When I work with at-risk science teachers to identify the skills, they employ to respond to students, and we compare their responses to highly effective teachers; we get no difference in that list. They identify the same “skills.” The difference is that the effective teachers know when, how, where, etc., to employ those skills. They understand how to use the look inside of a “gradient of intensity” (i.e., the glance, the look, the stare, and the glare). They get the idea of a “light pink” look, a “medium pink” look, a “dark pink, look, a “light red look,” etc. They don’t use a “dark red” when the situation requires a “light pink” (and vice versa). Effective science teachers get the “art of enactment.” That same idea of the “gradient of intensity” plays out with how they apply proximity, use a student’s name, etc. That gradient of intensity plays out as the student or students’ behavior escalates and the skills the teachers enact also become more sophisticated. That escalation is seen as “bumping it up”; as the student bumps up the situation, the teacher has to have a corresponding set of skills.

I don’t have the space in this entry to describe the following nine “bumps,” but they are simply logical responses to classroom situations. For example, Bump Three relates to effective choices with the follow through on the choice being Bump Four. Bump Five refers to power struggles. Bump Ten is when the student has made the decision to be expelled; the key with Bump Ten is that the student understands that he or she made that decision to be expelled, not the school staff. Classroom management is delightfully complex, our challenge is to make sure we become consciously competent (collectively), and not simply accidentally adequate (individually) in our thoughts and actions, to prevent and to respond to that complexity.

Cross-References

- ▶ Classroom Learning Environments
- ▶ Cooperative Learning
- ▶ Dilemmas of Science Teaching
- ▶ School Environments
- ▶ Teacher Craft Knowledge

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Code-Switching in the Teaching and Learning of Science

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Code-switching has been defined variously over time and in different contexts, since Haugen’s (1956) definition of code-switching as the ability of a bilingual to introduce unassimilated words from another language into his or her speech. It has since been defined as the alternation between two (or more) languages; the ability to segregate competing languages and switch between them when contextually appropriate; the movement by a speaker from one language to another; the use of more than one language in order to contextualize communication; and the habit of switching from one language to another. According to Setati (1996), code-switching involves a word, a phrase, a sentence, or sentences and cannot happen between monolinguals, only bilinguals. It is a skill that requires competence in more than one language.

For a long time, code-switching was regarded as an inferior form of engagement. However, research findings in both language teaching and cognition continue to show that code-switching can serve important functions to facilitate and contextualize communication. Its importance in education has been investigated. For example, a few decades ago, some argued that code-switching might be linked to lower intelligence levels. However, subsequent research showed that there was no significant relationship between code-switching and intelligence. It is now believed that the ability to switch between codes may help with conceptual organization or thinking about things in a new way. In other research, code-switching has been identified as one of the strategies used in coping with the challenges of teaching and learning in a language that learners (and sometimes teachers too) are not competent in. However, in spite of these merits, code-switching has its constraints. If not mediated appropriately, it may interfere with meaning-making and may have a negative impact on the learning process. Also, learners may find it difficult to navigate the two languages, especially if they are not sufficiently competent in the second language as is usually the case where the language of instruction is not the learners' first language. Since the ability to switch between codes is indicated in conceptual organization, it could be inferred that failure to navigate between the codes may interfere with conceptual understanding. Code-switching in science teaching and learning is under-researched (e.g. Probyn 2004; Rollnick 2000; Setati et al. 2002).

Cross-References

- ▶ Language and Learning Science
- ▶ Scientific Language

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Cognitive Abilities

- ▶ Assessment: An Overview
- ▶ Cognitive Acceleration
- ▶ Cognitive Demand
- ▶ Metacognition and Science Learning

Cognitive Acceleration

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Keywords

Cognition; Creative thinking; Critical thinking; Higher-order thinking; Thinking

Introduction to Cognitive Acceleration

Cognitive acceleration is a term used to describe an approach to pedagogy and a research tradition in science education that is based on two broad principles: (1) that there is a general intellectual function in children which develops with age and (2) that the development of this general intellectual function is influenced both by the environment and by maturation (Shayer and Adey 2002). Cognitive acceleration pedagogy sought to stimulate and advance students' general intellectual functioning beyond what would happen as a result of maturation through the use of specially designed thinking lessons. The intention of these lessons is to improve students' intellectual capacity, thus leading to an improvement in their ability to participate in the school curriculum and an improvement in their school achievement.

This entry has five sections. The first very briefly outlines the Piagetian theory underpinning cognitive acceleration, the second describes the development of the cognitive acceleration interventions, the third outlines the findings from evaluations of cognitive acceleration interventions, the fourth describes the structure of the intervention, and the final section raises relevant issues of professional development.

Piagetian Theory and Cognitive Acceleration

The pedagogy of cognitive acceleration is largely based on Jean Piaget's theory of cognition and his constructivist theory of epistemology. This is the subject of an extended entry in this encyclopedia (Piagetian theory). Piaget regarded the development of cognition as an active process in which the brain constructs a reality based on the stimuli received through the senses, rather than as a passive process in which the brain assimilates representations of phenomena in the environment. He viewed this active process as a structural adaptation that enables the human organism to interact with and assimilate stimuli to construct an understanding of the environment.

Piaget and his associates concluded that as cognition or thinking develops, it changes in qualitatively different ways. Concrete operations consist of schema of student behavior such as the ability to order and classify in simple ways and to conserve number and volume. The more advanced schema of formal operations includes the ability to control variables and understand equilibrium, probability, and formal modeling.

An extensive study in the 1970s of Piaget's levels of cognition within a student population of 12,000 from a wide range of urban, rural, and high and low socioeconomically ranked schools in England and Wales indicated that, by the age of 16, only 10 % of these students had attained the level of late formal operational thinking and a further 20 % a level of early formal operational thinking. The remainder of the sample remained at or below concrete operational thinking. This level of cognition is well below that predicted by Piaget's estimates (Adey and Shayer 1994).

Development of the Cognitive Acceleration Intervention

In order to understand scientific concepts and methodology at any depth, students need to have reached the level of formal operational thinking. For example, the use of the particle model of matter as an explanatory model requires early formal operational thinking. Students who have not reached this level may be able to memorize information about the behavior of particles and recall it when tested, but they will be unable to use the model to explain observed phenomena or write scientific explanations that demonstrate an understanding of the implications of the model. The development of formal operational schema enables students to systematically use forms of higher-order thinking which include multivariate, abstract thinking, compound variables, ratios and proportions, probability and its implications, formal scientific models, equilibrium, and correlation.

Adey and Shayer were concerned that, as above, 30 % of 16-year-old students were able to think at the level of formal operations. These researchers believed that the stages of thinking exhibited by a class of students are not fixed and that it is possible to teach students how to think in new ways. In response to these concerns, Adey, Shayer, and colleague Carolyn Yates developed the Cognitive Acceleration through Science Education intervention (commonly referred to by the acronym CASE and commercially known and referred to by many teachers as Thinking Science) (Adey et al. 2001). CASE is a program of 30 lessons designed to demonstrate to teachers how to stimulate student cognitive development and improve students' ability to understand science. The lessons are part of a professional development program that supports teachers over a 2-year period as they learn the pedagogical skills required to fulfill the purpose of the lessons.

Evaluations of the Cognitive Acceleration Intervention

CASE developed into one of the most widely employed and highly lauded programs for developing high school students' thinking ability in the United Kingdom (UK) and internationally. Considerable evidence has been published on the effects of the CASE strategies on children's cognitive development and school achievement (Shayer and Adey 2002). Research with over 2,000 high school students in 11 UK schools showed that after 2 years of participation, the proportion of students using high-order thinking was significantly higher than the national average. The statistically significant gains made by the CASE students over the national average were large, 0.67–1.26 standard deviations. There also is evidence of long-term transfer effects of CASE on scholastic achievement, even beyond the area of science. Improved student achievement in subjects other than science has been attributed to CASE having an effect on general intellectual growth, as well as on science-related thinking skills. The achievement gains were found for the full ability range of pre-intervention students. Independent reviews have supported these findings. Some researchers have noted the lack of attention to the students' attitudes and motivations in the CASE research (e.g., Leo and Galloway 1996).

The general approach to cognitive acceleration has since been applied to other disciplines, including mathematics and technology, and programs have been developed for younger children in the early childhood and middle primary years (Shayer and Adey 2002). Cognitive acceleration programs also have been successfully adapted and trialed in many countries.

Structure of the Cognitive Acceleration Intervention

Thinking Science lessons are structured around six pillars:

1. Concrete preparation: The teacher spends a short time explaining the purpose of the lesson to students and advising them of necessary procedures such as matters of safety.
2. Data collection: Students participate in a scientific activity. The data collected forms the basis of the challenge they will discuss.
3. Cognitive conflict: Cognitive conflict is one aspect of a Thinking Science lesson that drives cognitive development. It involves a challenging or difficult situation; for example, when the data students collect are different to what they expected, they are stimulated to think in new and different ways to comprehend the data.
4. Social construction: The challenging problem is discussed by students in a group of three or four. It is important that students are explicitly taught how to discuss, listen actively, and work constructively in a group. Social construction, which is a challenging discussion, is the second pillar that stimulates cognitive development.
5. Metacognitive questioning: Metacognition involves students reflecting on their own thinking and articulating the approaches they took to problem solving. This gives other students insight into different ways of thinking and evaluating. During the lesson, the teacher and students use metacognitive questions to probe thinking during discussion, for example, "Why do you think that? How did you work that out? What made you feel confused?" Metacognition is the third pillar that stimulates cognitive development.
6. Bridging is the process of contextualizing the problem discussed in a particular lesson. It enables students to relate what they have discussed to their everyday life or to other experiences they have been exposed to in science classes.

The teaching of higher-order thinking, and/or critical and creative thinking, is an underlying assumption of almost all current secondary science curricula across the globe. Examples of such thinking include critically analyze, deduce, evaluate, explain, justify, and synthesize. However, rarely is a definition of these terms provided, and teachers often are unaware of how to teach in ways to ensure their students are able to develop these higher-order thinking skills. Thinking Science pedagogy leads to this development that is also the basis of critical and creative thinking.

Professional Development of Teachers

As with all new pedagogical approaches, effective professional development is an essential pathway to the high-quality pedagogy required for cognitive acceleration. Professional development is defined as effective when it changes teachers' pedagogical practice and improves student outcomes (Adey 2004). Widely recognized problems in the provision of effective professional development include a lack of executive support, history of innovations with little or no theoretical basis, lack of ownership of teacher learning, scant acknowledgement of teachers' current contributions in the classroom, failure to consider the whole school context and the teachers' work within that context, no direction about how to recognize and build effective collegiality, and lack of long-term support while new pedagogical approaches are explored and adopted.

Thinking Science professional development has followed well-documented principles for effective professional development and attempted to resolve these problems in the following ways. School administrative support is gained before the implementation of the program; teacher ownership of the program is developed by providing an understanding of its theoretical basis and involvement in the analysis of its effectiveness. Professional development is long term including central in-service days and an emphasis on in-class coaching to support teachers as they practice and acquire new approaches to pedagogy over the 2 years of the program. Furthermore, the development of collegiality is encouraged for mutual support and sustainability of the program. Thinking Science professional development focuses on the development of effective student-centered pedagogy and on the relationship between this and improved student outcomes.

Cross-References

- ▶ Alternative Conceptions and Intuitive Rules
- ▶ Developmental Perspectives on Learning
- ▶ Piagetian Theory

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Cognitive Demand

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Keywords

Cognition; Information processing; Mental capacity; Mental demand (*M*-demand); Problem solving; Working memory; Working-memory capacity; Working-memory overload model

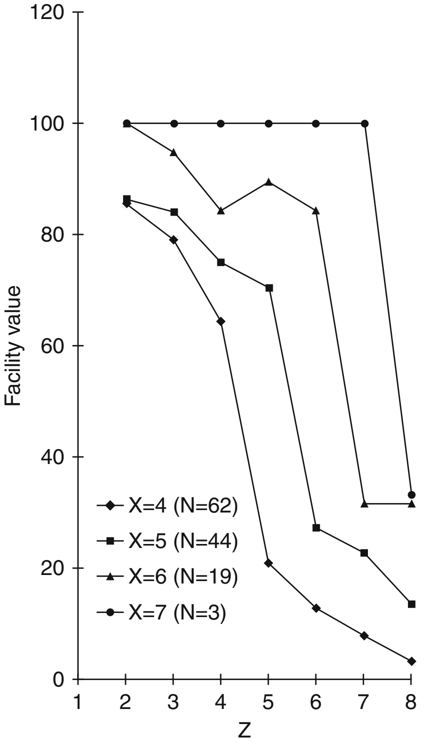
Cognitive demand or **mental demand** (*M*-demand) is a construct that is applied to the study of cognition and especially of problem solving. As such, it relates to science teaching, learning, and assessment of teaching and learning. In psychology and cognitive science, *cognition* relates to information processing, which in turn relates to a number of psychological or ► cognitive abilities or functions or variables (also called *psychometric variables*). Essentially, the cognitive demand of a mental task, such as a problem, is related to the complexity of the task/problem. In general, as a problem increases in complexity (in terms of what information has to be held and what process has to be performed), performance decreases. The complexity of a problem in science education is described by (a) the "*M*-demand" and (b) the "logical structure" of the problem. In this article, *M*-demand will be treated first.

The assignment of *M*-demand to a problem follows from the optional or minimum number of component steps required to accomplish the solution to the problem. This can be judged by comparison of the allocated *M*-demand by independent expert solvers of the problem. Another extended definition of *M*-demand is "the maximum number of thought steps and processes which have to be activated by the least able, but ultimately successful candidate in the light of what had been taught" (Johnstone and El-Banna 1986). The assigned *M*-demand of a problem can further be verified by a posteriori analysis of the students' solutions. This method is consistent with the four-step procedure for the evaluation of the *M*-demand known as *dimensional analysis* (Niaz and Logie 1993). In addition, the confirmation of the validity of the *working-memory overload model* can provide further support to the estimation of the *M*-demand of a problem (see below).

A central construct in information processing is that of *working memory*, of which a measure is provided by the *working-memory capacity* (Baddeley 1986). Alternatively, the construct of *mental space* is used, which is measured with the *mental capacity* (*M*-capacity) (Pascual-Leone 1970). Both the working-memory capacity and *M*-capacity variables are operationalized and measured by means of corresponding psychometric tests. Specifically, one way of assessing working-memory capacity is by means of the *Digit Backward Span Test*, which is part of the Wechsler Adult Intelligence Scale, while *M*-capacity is assessed by means of the Pascual-Leone's *Figural Intersection Test*.

A characteristic model involving working memory is the *working-memory overload model* (or hypothesis), which states that a subject is likely to be successful in solving a problem if the problem has an *M*-demand, which is less than or equal to the subject's working-memory capacity (W) ($M \leq W$), but fail for lack of information or recall, and unsuccessful if $M > W$, unless the student has strategies that enable him/her to reduce the value of M to become less than W (Johnstone and El-Banna 1986). Information processing relates then to a "holding/thinking space" (i.e., working memory), which has a finite limit, after which the decrease of achievement may be rapid. The rapid decrease in students' achievement has been connected to *working-memory overload* and has been usually demonstrated by an inverse *S*-shaped curve, which is the graph of the percentage of successful subjects as a function of the *M*-demand of a problem (see Fig. 1). For instance, from the graph for the working-memory capacity of 6, it follows that students with this capacity are, as a rule, successful in problems with *M*-demands of 2 up to 6, but fail when the *M*-demand assumes values of 7 and 8. The part of the curve with the largest slope is thought to correspond to the subjects' working-memory capacity overload.

Research has shown that the model was found not to apply to all kinds of empirical data, except for some specific cases. The following have been found to operate as limitations and necessary conditions for the model to be valid (Tsaparlis 1998): (a) the logical structure of the problem must be simple; (b) the problem has to be non-algorithmic; (c) the partial/component steps must be available in the long-term memory and accessible from it; (d) the students do not employ "chunking" devices (by means of which they



Cognitive Demand, Fig. 1 Facility value (%) in organic-synthesis problem solving versus *M*-demand (*Z*) versus various levels of working-memory capacity (*X*) for a sample of students ($N = 128$) without previous training in these problems (From Tsaparlis and Angelopoulos (2000), Reprinted with permission from Wiley)

chunk the problem into familiar chunks and thus are reducing the *M*-demand); and (e) no "noise" should be present in the problem statement; as "noise" is assumed the irrelevant and potentially misleading information that might be included in a problem.

In general, a sudden decrease in students' performance might occur not only because of the limitation of their working-memory capacity but also because of the interference of other variables; thus, it has been shown that psychometric variables, such as *disembedding ability* (degree of "field dependence/independence") and/or *logical thinking* (previously referred to as "developmental level" in the Piagetian sense), play an essential role in science problem solving. It is worth noting that in the working-memory model, field dependence is seen as a moderator variable: field-dependent subjects appear to possess lower working-memory capacity because they use part of their capacity to process irrelevant information. "Spatial ability," involving also disembedding of information, has also been found to affect student achievement in problem solving.

It was stated above that the complexity of a problem in science education is described by (a) the *M*-demand and (b) the logical structure of the problem. The *logical structure* is associated with the number of different *logical schemata*, which the solver has to retrieve from his long-term memory in order to solve the problem (Niaz and Logie 1993). According to Jean Piaget, a *schema* is an internal structure or representation (apparently in long-term memory), while the ways we manipulate schemata are called "operations." In ▶ Piagetian theory, schemata are continually growing and developing rather than remaining fixed. Describing thinking at various stages becomes thus an issue of trying to define the schema (or mental structure) and the operations (or internal actions) that a problem solver is using. In the case of chemistry, examples of logical schemata are chemical stoichiometry, gas laws, and the state of chemical equilibrium.

In a study about the validity of the overload hypothesis, organic chemical-synthesis problems were used, with a simple logical structure and varying *M*-demand from $M = 2$ to $M = 8$ (Tsaparlis and Angelopoulos 2000). In general, organic-synthesis problems are very difficult for the students, being very demanding in terms of information processing, because the number of pathways by which students could synthesize target substance "X" from starting substance "A" may be numerous. These problems are unique in that they can satisfy the necessary conditions that must be fulfilled for the validity of the tested problem-solving model (see above): they (i) exclude numerical or algebraic calculations, (ii) have a simple (one-schema) chemical logical structure, and (iii) cannot be answered by the application of an algorithmic procedure. The latter requirement is equivalent to them being real *problems* and not routine *exercises*. Two samples of students (ages 17–18) participated in the study: one sample had received some previous training in these problems, while the other sample had not. Although the predicted pattern was observed in both samples, it was found that the model was more useful in the case of the students without previous training (see Fig. 1). Finally, as expected, the model predicted better with the field-independent and the field-intermediate students than with the field-dependent ones.

The construct of *cognitive demand* or *mental demand* (*M*-demand) and its connection with *information processing* and other psychological functions have important implications for science teaching, learning, and assessment of teaching and learning. The findings of research can guide the construction of a series of problems in a science topic with the same reasoning pattern (the same logical structure) and varying *M*-demand. Student success, especially for novice learners, can be facilitated by the careful control of the *M*-demand, that is, by first introducing problems of low *M*-demand and by leaving problems of high *M*-demand for later use, when students have acquired experience and motivation. Teachers must feel their responsibility for this student transition: they must emphasize and consciously employ the relevant strategies throughout their teaching. Only when strategies have been learned should complexity be allowed to increase, so that students can learn to keep the value of *M*-demand (not the actual but their own modified by "chunking" *M*-demand) well within their working-memory capacity. In this way confidence, and hence motivation, can be maintained while complexity increases, leading novices toward the expert state.

Cross-References

- ▶ Information Processing and the Learning of Science
- ▶ Learning Demand
- ▶ Memory and Science Learning
- ▶ Piagetian Theory
- ▶ Problem Solving in Science Learning

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Cognitive Labs

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Keywords

Cognitive interviews; Protocol analysis; Talk-aloud protocols; Think-aloud interviews; Think-aloud protocols; Verbal analysis; Verbal protocol analysis; Verbal reports

Cognitive lab is a term frequently used to refer to a set of procedures and conditions (experimental situations) in which verbal reports are elicited and collected to study cognitive processes. Such verbal reports serve as a major source of data on the cognitive processes that subjects engage in when completing diverse tasks such as solving a problem, responding to a survey question, answering a test item, or reading different types of texts. Cognitive labs are used in diverse fields, but one in which it is frequently used is in the development and evaluation of assessments and questionnaires (or surveys).

Two issues are important to consider when discussing cognitive labs: (1) the necessity to focus on the actions intended to elicit and collect verbal reports and the information they provide about the inferred cognitive processes, rather than on the conditions in which they take place and (2) the liberal way in which certain words are used to refer to the methods to gather the verbal reports (e.g., think-aloud protocols, think-aloud interviews, talk-aloud protocols, verbal protocols, or cognitive interviews). Not all terms can be treated as equivalent and they impose their own characteristics to the experimental situation. The discussion of cognitive labs here is then centered on the issues related to verbal reports rather than the cognitive labs as a physical space or experimental situation.

Verbal reports have been considered by cognitive psychologists to be the available method that most closely "identifies the content of a person's mind..." (Leighton 2009, p. 2). A common feature to all the procedures used to obtain verbal reports is that subjects respond orally to an instruction or probe (Ericsson and Simon 1980, 1993). Two general procedures can be indentified for gathering verbal reports: protocol analysis and verbal analysis. *Protocol analysis* is often used to tap cognitive processes underlying the completion of a task; it helps to confirm cognitive models of task performance. *Verbal analysis* is used to tap knowledge structures; it helps to explore and generate cognitive models of task performance as well as beliefs and attitudes about the task at hand. Due to the space constraints, this entry focuses only on protocol analysis given the wide use of this procedure. For information about verbal analysis, see Chi (1997).

Protocol Analysis

Protocol analysis is guided by human information-processing models. It is used mainly for identifying, through verbalizations, cognitive processes involved in problem solving. These verbalizations constitute the verbal reports. Once they are transcribed, the verbal reports are referred to as the *protocols* (Ericsson and Simon 1993) that will be the subject of the *analysis*. Verbal protocols provide a source of evidence for tracing and documenting the representations and processes used by subjects to approach a task (e.g., generate a solution). These processes are compared to a hypothesized cognitive model of solution – a model of the possible logical sequences of cognitive steps needed to produce a correct response. In other words, protocol analysis helps to *confirm cognitive models* of task performance (Leighton 2009).

There are two types of verbal reports:

1. *Concurrent verbal reports*, in which subjects are instructed to verbalize their cognitive processes as they work through (or perform) a task. Talk aloud and think aloud are different forms of verbal reports that can be produced in concurrent verbalizations. Each represents different levels of information processing. In the talk aloud, the verbalization is direct; the subject verbalizes or reproduces the information as she or he is attending to the information. In the think aloud, the verbalization is mediated by another type of processing. The instructions to the subjects are also different: "Talk aloud as you multiply 24 times 36!" versus "What is the result of multiplying 24 times 36?"
2. *Retrospective verbal reports*, in which subjects are instructed to verbalize, retrospectively, the sequence of thoughts that occurred during the performance of a task. Ideally, retrospective reports should be done by the subject immediately after the task is completed since most of the information will still be stored in the short-term memory.

Conditions for Protocol Analysis

Experimental situation. Minimizing social interaction is critical to collecting verbal reports through protocol analysis. For example, the researcher or data collector should be seated behind and not visible to the participant. The rationale for this arrangement is that socially motivated verbalizations require additional cognitive processing to present the verbalizations in a coherent and understandable manner, which might affect the sequence and depth of thoughts (Ericsson and Simon 1993). Hence, when subjects are reminded to talk or think aloud, the preference is to instruct them to "keep talking" rather than saying, "please tell me what you are thinking" or "what are you thinking?"

Selection of tasks. Tasks used in protocol analysis should have a clear focus and avoid vagueness. This helps to ensure not only that subjects will be fully engaged while completing the tasks but also that the cognitive model of the task can be more easily developed. When subjects are fully engaged in the task, it is more likely that their verbalizations follow the same sequence of thoughts as occurring in a silent condition (Ericsson and Simon 1993).

Critical to protocol analysis is the identification of the cognitive model that is expected that subjects will use to approach the task at hand (the knowledge of the cognitive demands imposed by the task assigned to the subjects). This knowledge can be obtained through *task analysis* – the specification of the logically possible sequences of cognitive steps to produce a correct response (i.e., the solution path or the cognitive model of the task). Task analysis is usually conducted by experts.

When verbal reports are used in the context of assessment (mostly for validation purposes), another condition is required: tasks selected for verbal reports should be of *moderate difficulty* relative to the population of interest (Taylor and Dionne 2000). This moderate level of difficulty allows for more *controlled cognitive processing* – awareness of how the task is being approached. Easy tasks elicit rapid recall (automatic cognitive processing), leaving the subject unaware of how he or she approaches the task. On the other hand, difficult tasks may overload the working memory by exhausting all the mental resources in responding to the task, such as understanding the task, retrieving information from long-term memory, and selecting appropriate strategies to approach the task. With all the working memory occupied by these activities, few if any mental resources will be available for concurrently articulating verbally the cognitive processes involved in approaching the task.

Instructions. Critical to the generation of valid verbal reports is the nature of the instructions provided. Instructions need to be carefully worded because they can influence the nature of the verbal reports (Ericsson and Simon 1993; Tyler and Dionne 2000; see examples of instructions for talk aloud and think aloud in the concurrent verbalization section). The instructions for protocol analysis should emphasize general reporting of the participants' thoughts, and they should not include requests to report specific aspects related to the explanation or justification of responses (see conditions below). It is important to remember to use "keep talking" to remind the subject to talk rather than any other form that invites for social interaction.

Ericsson and Simon (1993) suggest the use of a couple of easy warm-up tasks which cognitive processes are well known but are not associated with the task at hand (e.g., "Talk aloud as you tie your shoelaces."). Warm-up tasks are intended to ensure that the instructions for generating appropriate verbal reports are understood. They are also intended to reduce anxiety and make subjects more comfortable in the experimental situation.

Analysis of Verbal Protocols

Steps for analyzing verbal protocols can be summarized as follows (Ericsson and Simon 1993; Taylor and Dionne 2000): (1) Transcribe the verbal report verbatim; transcriptions should capture as much detail as possible (e.g., pauses, emphases, tone). (2) Develop a valid coding system, based on the cognitive model of the task, to identify the processes and patterns of knowledge in the verbal data collected. The level of detail of the coding system will vary accordingly. It is important to remember that task analysis plays a critical role in the development of coding systems. This analysis along with the generation of the cognitive model of task performance constitutes a significant portion of the work required to segment and code the verbal protocols. (3) Segment the verbal protocols in units that will be the focus of the analysis, what will be coded. Ericsson and Simon (1993) suggest segmenting the protocol by statement. However, the segments can be aggregated to conduct other types of analysis (e.g., by episode or major process or steps in solving the problem). (4) Code each segment at the level suggested by the coding system. The complexity of the coding system will determine the number of codes applied to each segment. (5) Evaluate the reliability of the coding system. Clearly defined codes illustrated with prototype examples help to increase the consistency across coders. (6) Develop a complete model of the subject's cognitive procedures reported in the verbal reports that reflect the problem-solving process. Such models can be a description of the interconnection of the problem-solving stages or a pictorial model such as a decision tree graph (Ericsson and Simon 1993) or flowchart (Gierl et al. 2009). Graphical representations of the verbal protocols are used to match the path the subject took with the sequence of steps specified in task analysis and reflected in the cognitive model.

Limitations of Verbal Reports

The use of verbal reports raises three critical areas of concern (Wilson 1994): (1) *Completeness* refers to the difficulty of determining with certainty the completeness of a verbal report. Even in concurrent verbalizations, verbal reports can become incomplete if the cognitive processes cannot be easily verbalized, for example, when certain cognitive processes have become automatic. (2) *Reactivity* refers to the potential interference in the cognitive process when participants are asked to verbalize their thoughts – reactivity may change the cognition of interest, leading to a misinterpretation of the subject's cognitive processes. (3) *Non-veridicality* focuses on the issue that simply asking someone to verbalize their thoughts does not guarantee access to the cognition of interest, which may lead to misunderstanding their cognitive process. Still, a fourth concern can be mentioned inherent to protocol analysis; it is *costly* and *time consuming*.

To minimize the concerns raised above, three actions are recommended (Ericsson and Simon 1993; Taylor and Dionne 2000): (1) Use the two forms of verbal reports, concurrent and retrospective, as complementary methods to obtain a more complete picture of cognitive processes. The former helps to identify the knowledge and skills being used to approach the task; the latter helps to elaborate or clarify what was found in the concurrent reports. Retrospective reports also can be used to gather information about participants' metacognitive knowledge (Taylor and Dionne 2000). (2) Once the participants finished the task, do not wait too long to obtain retrospective verbal reports. What subjects remember, and how well, will generally depend critically on the interval between the moment the information is being processed and the moment of recall (Ericsson and Simon 1980). (3) For think-aloud verbal reports, do not allow subjects to rationalize or conjecture as they are engaged in the task.

A Final Note

It is important to acknowledge that cognitive labs are implemented in many different ways. The procedures used have become a big array of practices, and the names used to refer to these practices are now a complex combination of terms previously used for other purposes. This state of affairs is also due to the lack of effort from the research community to incorporate and clarify the use of terms in a more accurate way. An effort toward this end is needed not only to avoid confusion in the procedures used but also to have clarity about the inferences made based on the verbal reports. Inferences made about subjects' cognition depend on the type of procedures conducted and the type of verbal report collected.

Cross-References

- ▶ Alternative Conceptions/Frameworks/Misconceptions
- ▶ Laboratories, Teaching in
- ▶ Language and Learning Science

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Cognitive Preferences

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Keywords

Cognitive style; Conceptual understanding; Learning style

Cognitive Preference is a particular form of cognitive style that has at times in the last 50 years been a significant component of aspects of research on science learning. It was particularly prominent in research in the 1960s and 1970s because of strong logical links between the construct and the changes in emphasis to conceptual learning that characterized the dramatic developments of science curriculum and curriculum projects in the late 1950s and 1960s in the Anglophone world.

"Cognitive Style" (or, sometimes, "learning style") describes the notion that individuals have consistent patterns in the forms of information they seek and the ways they then gather and process this information. While there is continued debate about the extent to which any individual consistently behaves in this regard and as to the extent to which such consistency is a singular or multiple dimension of the individual's characteristics, cognitive style in a range of forms is a concept of significance in scholarship relating to human learning and behaviors (particularly in studies in the fields of education and management).

The curriculum projects of great influence in the late 1950s and 1960s began with PSSC Physics, closely followed by CHEM Study and BSCS Biology. These are often referred to as the First Generation projects or the "alphabet phase" of large-scale science curriculum development. These projects were all strongly characterized by a focus on conceptual content and developing student understanding of these concepts and a clear move away from descriptive, applied, and historical aspects of science. This focus on conceptual understanding as the most significant learning outcome to be sought went as far as attempting (sometimes implied, occasionally explicit) to more generally change the intellectual approaches of students towards a seeking of understanding in all contexts. This led quickly to Heath, a psychologist specializing in educational measurement, constructing in 1964 the notion of Cognitive Preference.

Cognitive Preferences were seen by Heath to be particular modes used by students in learning science (dealing with scientific information). He identified four of these modes:

1. Recall (R): Acceptance of information without consideration of implications, applications, or limitations.
2. Principles (P): Acceptance of information because it exemplifies or illuminates a fundamental scientific principle, concept, or relationship.
3. Questioning (Q): Critical questioning of information regarding its completeness, generalizability, or limitations.
4. Application (A): Emphasis on the usefulness and applicability of information in a general, social, or scientific context. Any student was seen to be consistently more inclined to use one of these modes above the other three.

Explorations of Cognitive Preference then quickly became very common in a range of approaches to researching the First Generation curriculum projects, from large-scale curriculum evaluation studies to studies of individual science learning that resulted from the use of the curricula. Assessment of an individual's cognitive preference has, I believe, always been done via pencil-and-paper testing. Questions on these tests always follow the same format:

– An introductory statement that relates to some aspect of the curriculum content that is the focus of the study is followed by four statements that extend or elaborate the introductory statement, with each of these four corresponding closely to one of the four modes of cognitive preference described by Heath.
– It is noted that all the four extension/elaboration alternatives are correct statements and the respondent is asked to either (i) select the statement they find most appealing or they would most like to learn more about, or (ii) rank all four statements (in terms of appeal or most like to learn more about), or (iii) choose both the most and the least appealing statements (or more/least like to learn more about).

The following is a typical Cognitive Preference test item:

> The pressure of a gas is directly proportional to its absolute temperature.
> (a) The statement as given above fails to consider effects of volume changes and changes of state.
> (b) Charles' or Gay Lussac's Law.
> (c) The statement implies a lower limit to temperature.
> (d) This principle is related to the fact that overheated automobile tyres may 'blow out' (Tamir 1985, p.2).

In this item option A corresponds to the mode Questioning (Q), option B to Recall (R), option C to Principles (P), and option D to Application (A).

Individual research studies using Cognitive Preference tests have consistently reported high reliabilities for these instruments. In his 1985 review and meta-analysis of then approximately 100 extant science education studies involving cognitive preferences, Tamir concluded "…the results reported here indicate that the cognitive preference construct demonstrates a reasonable level of validity, that Cognitive Preferences make significant contribution to learning, and that their inclusion in further educational research as well as their consideration in educational practice is to be encouraged" (p. 13). Despite this exhortation studies that include the construct, Cognitive Preference has been extremely rare since this time. It is almost certain that this is due to the moves that began in the early 1970s to expand the intentions of the science curriculum beyond the essentially singular focus on conceptual understanding that characterized the First Generation projects.

Cross-References

▶ Curriculum Movements in Science Education
▶ Inquiry, As a Curriculum Strand

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Coherence

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Keywords

Assessment; Formative assessment; Learning progressions; Summative assessment

Assessment may serve different purposes in different contexts. In the context of classroom learning, teachers use assessment to collect information about students' competence in a particular domain (e.g., science) at the beginning of and throughout an instructional unit for planning and monitoring student learning. At the end of the unit, the school year or even a particular stage of education, teachers use assessment to collect information about student competence to evaluate the outcomes of student learning in scope of the unit or school year. In the school, district, state, or national level context, assessment is used for monitoring student learning across multiple school years. All these assessments may be considered to serve the eventual aim to improve student learning. However, only assessments that have an immediate effect on the assessed students' learning are considered formative assessment. Assessments used for certification purposes (e.g., grading) and monitoring purposes (e.g., comparing different curricula) are considered summative, as these assessments typically aim to comprehensively assess student competence in a domain without an immediate impact on student learning. Still, such assessments – better: the information obtained through these assessments – are utilized to send students to a school track that suits their level of competence the best. Or these assessments may be used to increase funding for those school districts whose students have been found to fall behind in mastering the required level of competence at a particular stage of their educational career. Sometimes the same assessment is used for different purposes. Teachers, for example, may use assessments carried out for certification purposes (e.g., an end-of-year test) and also for formative purposes (e.g., to plan student learning in the following school year).

However, while a single assessment can be meaningfully used for more than one purpose, that does not mean that one assessment can serve all purposes (National Research Council [NRC] 2001). Assessments need to be designed to first and foremost serve the purpose they are intended for. Formative assessment in the context of the classroom is typically designed around rich tasks that require the application of a combination of in-depth knowledge (e.g., an understanding of the core ideas of science) and complex skills (e.g., scientific practices). Summative assessments in large-scale contexts on the other hand typically build on multiple-choice items for more efficient scoring. And whereas information obtained through multiple-choice large-scale summative assessments can be used for formative purposes, for example, at the beginning of a unit, the information will not provide in-depth information of student thinking and as such is not suitable for monitoring student learning throughout a unit. In order to ensure that – despite their design to fit different purposes – the various assessments used within an education system all serve the eventual purpose of improving student learning, coherence needs to be established across the different assessments (NRC 2014).

Assessment should build on three foundational elements: a model of student competence development, a set of beliefs about typical tasks or situations students at each level of competence development can solve, and a set of (statistical) procedures to aggregate the information aimed for from the raw data. As the latter two elements are specific to the purpose the respective assessment serves, the first foundational element is the one by which to establish coherence. A comprehensive model of student learning about a domain (e.g., science) is needed that describes student learning at different grain sizes, across multiple-grade bands, within one grade band, from lesson to lesson, and even within one lesson. That is, multiple models of student learning about different aspects of the domain are required describing learning at the smallest meaningful grain size. These models then need to be integrated into a system which allows to describe student learning across time as a function of the content taught. So far, science education research has provided many assessments that can describe student learning on smaller timescales. What is missing is an empirical foundation for larger models of student learning that can align the structuring of content (i.e., curriculum) across several grade bands and serve as a framework for aligning assessments both horizontally and vertically (NRC 2006). This function is to be fulfilled by learning progressions (e.g., Wilson 2009, p. 727).

Cross-References

- ▶ Assessment: An Overview
- ▶ Formative Assessment
- ▶ Learning Progressions, Assessment of
- ▶ Summative Assessment

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Collaborative Learning in Science

▶ Cooperative Learning

Communicating Science, Classroom Assessment of the Ability to

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Introduction

Scholars of science education have become increasingly interested in the classroom assessment of science communication ability. This interest is partially due to a growing realization that effective science instruction leads to improved communicative ability. In addition to mastering important science concepts, learners also develop a variety of communicative skills such as an improved ability to talk, write, argue, and reason scientifically. The following text introduces readers to scholarly work in which such communicative outcomes have become the object of classroom assessment efforts. Attention is given specifically to the different ways that classroom science communication is conceptualized and methodologically approached as part of science classroom assessment efforts. In some studies, science learners are viewed as developing the ability to express their thoughts in the language of science, and what is assessed is their ability to "talk science." In others, science classroom communication is viewed rhetorically, and what is assessed is students' competence in oral argumentation.

Talking Science

Classroom assessment of students' ability to talk science has been largely informal and formative, typically being conducted in the context of whole-class discussions at elementary grade levels. These oral assessment efforts are strongly influenced by the book *Talking Science* where Lemke (1990) identifies the stylistic norms to which speakers must abide in order to talk "proper science" in classroom settings: 1. Be as explicit and universal as possible. . . 2. Avoid colloquial forms of language. . . 3. Use technical terms. . . 4. Avoid personifications and. . . human attributes or qualities. . . 5. Avoid metaphoric and figurative language. . .6. Be serious. . .7. Avoid personalities and reference to individual human beings and their actions. . .8. Avoid reference to fiction or fantasy. . .9. Use causal forms of explanation and avoid narrative and dramatic accounts. (p. 133)

Lemke conceives of science as a school subject whose communication requires mastery over a specific register, that is, a specialized and context-specific variety of the English language. This characterization of "the language of science" has been used in recent studies as a basis to assess the effectiveness of elementary teachers' oral strategies in encouraging students to talk scientifically (i.e., make use of the scientific register). Pappas et al. (2003) describe how primary students tend to recount previous events and experiences in a generalized and impersonal manner when allowed to make spontaneous and unprompted contributions to the discussion during a loud reading of science trade books. Oliveira (2010) reports that referential questions (i.e., student-centered oral queries that require pupils to express their own conceptual understandings) prompt long, explicit, and precisely articulated student responses. Oliveira (2011) identifies provision of participant examples (oral descriptions of actual or hypothetical situations wherein the teacher presents himself/herself and/or students as characters to illustrate topics under discussion) with the generalized "you" as a strategy effective in encouraging students engaged in oral discussions to speak in a generalized manner consistent with the scientific register.

As a dynamic, continuous, qualitative, and formative endeavor, classroom assessment of students' ability to talk science informs subsequent teacher moves (reactive comments, follow-up question, and feedback provision). However, the feedback given to students is often too implicit and hence of limited informational value to pupils. Rather than explicitly commenting upon students' emergent ability to talk science, teachers tend to simply communicate their positive evaluation by indirect means such as pleased face expressions, affirmation (selective endorsement of student ideas), and topic uptake (selective follow-up on student ideas).

Arguing Scientifically

The literature on classroom assessment of students' ability to argue scientifically is considerably larger and more diverse. Focused on the rhetorical dimension of classroom science communication, a large number of studies have been conducted aimed specifically at assessing the quality (i.e., soundness and logical coherence) of students' science arguments by examining the extent to which they align with generic models such as Toulmin's Argument Pattern or TAP. This rhetorical type of assessment usually entails identification of argument components such as data, claim, warrant, backing, qualifier, and rebuttal.

Some studies focused specifically on the structure, justification, and content of arguments or student-generated products. Sampson and Clark (2008) used a variety of criteria (soundness, acceptability, coherence, correctness, and epistemic status) to assess an artifact written by a middle-school student to explain the thermal sensation of different objects (wooden, metallic, etc.). This study highlights how the same argument can be assessed as strong or weak and of high or low quality depending on whether the assessment is conducted from a perspective that is domain general, domain specific, content focused, or structure focused.

Others examined the process of argumentation or argumentation discourse, that is, the dialogic or interactional processes utilized by students to orally propose and justify arguments through whole-class or small-group discussions. In many of these studies, assessment was aimed at determining the quantity of scientific argumentation in science discourse. Erduran et al. (2004) quantitatively assessed small-group argumentation by determining the relative frequencies of five different levels of argument. High-quality arguments were operationalized as being extended and composed of multiple rebuttals, whereas low-quality arguments were limited to claims and counterclaims.

In many studies, quantitative assessment was combined with the construction of visual representations of classroom oral argumentation designed to visually assess the soundness and rhetorical quality of student arguments. Maloney and Simon (2006) used "discussion maps" to assess the relative levels of rhetorical sophistication of small-group discussions among 10- and 11-year-old students in the UK. This visual assessment method led to the identification of different levels of argumentation, including sustained evidence-based argumentation (highest rhetorical quality), series of arguments, repetitive and dispersed argumentation, and discussions without arguments.

Conclusion

In sum, classroom assessment of science communication can take varied formats (qualitative, quantitative, verbal, visual, etc.) depending on whether emphasis is placed on communicative style (manner of talk) or interpersonal persuasion. This trend suggests that science classroom communication serves two distinct and often competing communicative goals: expressive and rhetorical. Therefore, care must be taken to ensure alignment between the particular communicative goal being pursued and the assessment strategies adopted to determine its achievement as a result of science instruction and learning.

Cross-References

- ▶ Assessment of Doing Science
- ▶ Communicating Science, Large-Scale Assessment of the Ability to
- ▶ Discourse in Science Learning
- ▶ Discussion and Science Learning

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Communicating Science, Large-Scale Assessment of the Ability to

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Introduction

At the international level, research on large-scale assessments of science education has focused on two distinct aspects of science communication. The first body of work is concerned with how science is communicated to test takers and the potentially adverse impacts that particular communicative patterns can have on international comparisons of student performance in science. The second area of research deals specifically with students' ability to communicate science content to assessors when writing in response to short open-ended test items.

Communicating Science to Test Takers

Research in this area has examined both verbal and visual aspects of science communication in international assessments. Ercikan (1998) examined the IES science test, a large-scale examination given by the International Association for the Evaluation of Educational Achievement to Canadian students. The IES test was developed in English and then translated into French. Differential Item Functioning (DIF), a statistical analysis that controlled for differences in student ability, indicated that 26 % of the 70 test items were linguistically biased, that is, favored speakers of a particular language due to poor translation (e.g., replacement of unfamiliar science terms with everyday expressions, word choices that hinted at the answer, varied degrees of sentence complexity, etc.). The specific ways that each language was used to communicate science to test takers differentially affected their performance, thus undermining the equivalence and comparability of test items across languages. Hatzinikita et al. (2008) reported that the way that scientific knowledge was communicated in PISA science test items and Greek school textbooks differed both verbally and visually. PISA science materials combined nonspecialized, everyday language with highly specialized forms of visual representation (abstract images designed according to scientific visual conventions, symbolism, and notation), whereas the exact opposite combination (specialized language and everyday/realistic imagery) was predominant in school science textbooks.

Writing Answers Scientifically

This body of work has given attention specifically to students' ability to provide scientific explanations in international assessments. Combining both structural and conceptual assessment criteria, Zuzovsky and Tamir (1999) examined written explanations provided by Israeli students (fourth and eighth grade) in response to short-answer science questions on the TIMSS examination. Their findings reveal that student communication of scientific explanations usually takes the form of poorly articulated verbal accounts that are often incomplete, highly fragmented, simplistic, and devoid of specialized scientific terminology. The authors emphasize that many students have difficulty in producing scientific explanations for the purpose of exhibiting and demonstrating their conceptual understanding in large-scale assessments. However, it remains somewhat unclear whether the issue is one of conceptualization (student inability to conceptualize according to scientific principles) or communication (student inability to communicate their ideas scientifically). In a more recent study, Frändberg et al. (in press) examine students' written responses to two constructed response items from the Swedish part of TIMSS 2007 and report that only 10 % (86 out of 954) of the answers explain physical and chemical changes in matter at the submicro level (contained explicit references to atoms, molecules, or particles). Evidence is provided that, without careful and explicit prompts from assessors, student written communication of scientific knowledge and ideas in large-scale assessment is predominantly limited to the macro level (i.e., focus exclusively on perceptible and tangible properties and aspects of natural phenomena rather than microscopic entities).

Conclusion

In sum, the above studies problematize the relationship between content and form (communicative format) in large-scale science assessments. The reported findings challenge the general assumption that what is being assessed and compared in international testing is scientific content knowledge and not science communication ability (students' ability to interpret and produce scientific texts). Student performance across languages and countries may reflect student (in)ability to engage with certain forms of science communication rather than mastery of science concepts, thus deserving more careful consideration and critical analysis on the part of international test developers.

Cross-References

- ▶ Assessment of Doing Science
- ▶ Communicating Science, Classroom Assessment of the Ability to
- ▶ Discourse in Science Learning
- ▶ Discussion and Science Learning

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Communities of Practice

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The idea of communities of practice (COP) emerged from sociocultural traditions of research in education, anthropology, and sociology and is a fundamental element of situated learning theory. Situated learning offers a perspective on learning that prioritizes the contexts in which thinking, doing, participating, and learning take place. This focus on context should not be simply construed as environments having superficial influence on activities, but rather that learning is fundamentally associated with engagement in social practice. Here, the idea of social practice denotes more than interactions among multiple individuals; it is a characterization of human activity such that practices are embedded within systems of social expectations, norms, and negotiated meanings. In other words, social systems give rise to and afford meanings to practice and learning. The social systems that emerge relative to particular tasks, problems, or activities are communities of practice. Therefore, all knowing and learning are situated, and communities of practice define, in large part, the situational realities that shape the knowing, learning, and activities that can transpire.

It is important to note that communities of practice do not just provide a referent to opportunities for group learning. COP offer a theoretical orientation to the basic nature of knowledge and learning. Jean Lave and Etienne Wenger first introduced the notion of situated learning and COP in an attempt to formulate a new theory of knowing, doing, and learning that accounted for their anthropological observations of communities and how individuals developed expertise in these communities. In their seminal work on the topic, they define a community of practice as

> A set of relations among persons, activity and the world, over time and in relation with other tangential and overlapping communities of practice. A community of practice is an intrinsic condition for the existence of knowledge, not least because it provides the interpretive support necessary for making sense of its heritage. Thus, participation in the cultural practice in which any knowledge exists is an epistemological principle of learning. (Lave and Wenger 1991, p. 98)

Defining Elements of Communities of Practice

Three basic elements comprise communities of practice: (1) a community, (2) a domain, and (3) practice. The community references a group of practitioners who come together through interactions. Such a community may interact physically, but interactions can also be facilitated through virtual tools. So, communities do not necessarily need to share physical proximity, but they do need to facilitate actual interactions among the practitioners. A single teacher accessing a static lesson plan through a website is not participating in a community with the author of that lesson plan if there are no ways for these teachers to share ideas, respond to one another, collaborate, etc. We could generate a near-infinite list of possible communities relative to the science education enterprise. To help illuminate some dimensions of communities of practice, I suggest three such hypothetical communities: a middle school science class, a group of science teachers working together within an online professional development program, and scientists conducting research in a particular subdiscipline of biology. In the case of the middle school science class, a group of students and their teacher are the primary members of the community, although there may be other community participants depending on the role school administrators and others such as teacher aides or class volunteers may play. This community likely comes together on a near-daily basis, and creation/dissolution of the group is mediated by the academic calendar. A community of science teachers participating in an online professional development program may never interact in a face-to-face format, but they have opportunities to interact dynamically through Web-based tools.

A community of scientists contributing to the same research subdiscipline likely come together periodically through venues such as annual conferences, but they also interact through peer review processes, Web-based networking, and personal communications. Whereas the other examples of communities may have a naturally defined period of existence, the community of scientists may persist indefinitely or at least as long as the subdiscipline has interesting questions to pursue. The mechanisms for communication, size of the groups, and temporal dynamics of these communities may vary, but they share commonalities in terms of bringing people together with shared interests.

Communities of practice are more than just a group of individuals; a COP develops with respect a particular domain. The domain references the area of interest around which individuals come together. The idea is that COP do not emerge from random groupings, but rather are built by a network of people with shared interests and who are pursuing related goals. Each of the hypothetical community examples presented above is organized around particular domains. The middle school class comes together around the goal of learning science. This may be an idealistic representation of a middle school science class; critics may argue that this community is more interested in navigating the disciplinary and social expectations of the school and this may very well be the case for most middle school classes. In either case (and for other interpretations including those in which members of the community may have a combination of these and other intents), the community is organized around a domain. For the online teacher community, the domain relates to improving teaching practices, and the domain for the scientist community is defined by the focus and research questions driving their subdiscipline.

The third element is practice. Here, the focus is on the idea that individuals, who organize around a domain, engage in particular activities, access particular resources, use similar tools, etc. Communities of practice are not static assemblages of individuals who just happen to share a common interest, but rather are dynamic and necessarily involve participation. Referring back to the science education examples, the middle school class engages in shared practices such as routines related to things like taking notes and completing laboratory reports. Most classes have particular repertoires of acceptable (and unacceptable) activities that may involve use of classroom equipment, access to technology, and classroom discourse. Similarly, the teachers participating in online professional development will likely engage in community-specific practices such as the sharing of lesson plans and activities, sharing feedback with one another, interacting with new materials, etc. The scientific researchers employ various methods that have been negotiated through the community such that shared perspectives on standards for and the validity of evidence are evident (at least internally) and shared (although these shared perspectives may also be challenged).

Wenger, highlighted above as one of the scholars who introduced situated learning, continued to theorize about the conceptualization of communities of practice. He defines the COP construct in terms of three constitutive ideas that map to the three elements just presented: mutual engagement, joint enterprise, and shared repertoire (Wenger 1998). Mutual engagement highlights the social norms and expectations that define community structure. Joint enterprise represents the shared focus of group participation, that is, the domain of the community. Importantly, this joint enterprise is defined and continually refined by the community. The shared repertoire of a community consists of the resources, tools, protocols, and negotiated standards for practice. Here again, this repertoire is dynamic and can be continually renegotiated.

Communities of Practice and Learning

A community of practice perspective defines learning in terms of community-specific activity. A community member learns as she participates in the culturally mediated activities of the community. Lave and Wenger (1991) offered legitimate peripheral participation as a construct to account for social practice, which necessarily includes learning, within communities of practice. Legitimate peripheral participation provides a way to think about how community members with varying levels of experience (e.g., newcomers to the community versus more established old-timers) participate in the community. As newcomers develop understanding of community norms and expectations for participation as well as appropriate tools and processes for participation, they move toward "full participation" (Lave and Wenger 1991, p. 37). This trajectory of participation constitutes learning.

Whereas engagement in community-defined practices represents a fundamental aspect of learning, the identities that members create/assume within the context of their community determine the kinds of practices in which they can engage. There is a co-constitutive relationship between practice and identity, but importantly, practice and identity interact in dynamic ways such that an individuals' repertoire of practice and identity shift over time. A note on the use of identity is warranted: identity is a widely used construct across the social sciences and takes on various meanings depending on the framework used to define it. Sociocultural perspectives suggest that identity represents processes of positioning within a particular COP and this positioning is shaped by history and norms of the group. Therefore, this process and ultimately the identities that individuals assume (or create) are constructed together by the individuals and influential others within the community. As newcomers and their communities construct identities, the newcomers develop evolving views about competencies and potential relative to the community's domain making it possible for them to understand, use, and engage with disciplinary ideas and tools in new ways. From this perspective, identity construction is central to appropriating community practices and therefore is a fundamental aspect of learning.

COP as a Research Framework

Communities of practice offer a way of thinking about what it means to know, engage in activity, and learn, and this perspective has been used to frame science education research. In the final section of this entry, I introduce five recent studies, from major research journals in the field of science education. All five studies utilize COP as a construct to define and/or analyze problems related to the teaching and learning of science. This is not a comprehensive or even representative sampling of research framed in terms of COP. The presentation offers some examples of the diverse ways in which researchers have conceptualized and used COP. Table 1 presents citations for the five studies and abbreviated descriptions of each study's focus and main findings. In the table, I also describe the COP studied in terms of the three basic constitutive elements introduced above: community, domain, and practice.

The five articles showcase different kinds of communities of practice relevant to science teaching and learning. Feldman and colleagues (2013) study science research groups and explore how undergraduate and graduate students learn through apprenticeship in these groups. This research, which explores how newcomers to an established community appropriate community norms and practices, is highly consistent with Lave and Wenger's studies of apprenticeship that served as the basis for conceptualizing situated learning and communities of practice. Olitsky (2007) explores how a class of middle school students and their teacher shape interaction rituals within their classroom-based COP. Saka and colleagues (2013) study the phenomenon of new teacher induction by conceptualizing a first year teacher's experiences in terms of his enculturation in the school's community. This article provides an interesting case in which the community newcomer has expectations and anticipated practices that contradict community norms. These tensions have important implications for the identity the new teacher constructs. Kisiel (2009) presents a study of interacting communities of practice. Potential connections between an elementary school and an informal science institution are easy to draw in theory, but Kisiel's

Communities of Practice, Table 1 Examples of science education studies that have utilized communities of practice to frame the research

Citation	Focus	Community	Domain	Practice	Key findings
Akerson et al. (2009)	Development of a COP for elementary teachers learning about nature of science (NOS) and how to teach NOS	17 elementary (K-6) teachers, a science education faculty member, and three graduate students	Teaching NOS ideas to elementary students	Engagement in a summer institute, monthly workshops, use of explicit NOS activities, formal reflection on classroom practices	Participation in the COP supported development of NOS ideas and improved NOS teaching. NOS modeling and explicit reflection were needed to achieve these gains
Feldman et al. (2013)	Build understanding of how graduate and undergraduate students learn to do scientific research while participating in science research groups	Graduate students, undergraduates, postdocs, and faculty members working on a particular scientific problem	The study documented three COP with unique domains: microbiology, geology, and hydrology	Weekly group meetings, journal club, various scientific procedures, field work	Advanced students provided much of the mentoring for newer students and hypothesized a progression of positions within a research COP: novice researchers, proficient technicians, and knowledge producers
Kisiel (2009)	Explore a partnership between a school and an informal science institution and how implementation of the collaboration impacts stakeholders and students	Two COP are investigated: (1) a new elementary school and (2) an aquarium education department	(1) Establishing a new school and supporting student learning	(1) Teach science 1 day per week (lessons are typically repeated in successive years)	Boundary objects (artifacts shared across the COP) and brokers (key individuals who mediated connections) facilitated the creation of an overlap between the two COP
			(2) Outreach and education programs for school groups and the public	(2) Teach the same lesson to many school groups	
Olitsky (2006)	Ethnographic exploration of teaching practices and classroom environmental factors that support positive "interaction rituals" such that solidarity, feelings of group membership, and interest in learning were achieved	33 grade eight students and their science teacher. The students were racially diverse and came together in an urban magnet school	Learning physical science concepts and developing interest in science	Engagement in class discussions, hands-on laboratory activities, group problem-solving, linking science ideas to areas of student interest (like sports)	Classroom conditions that supported positive interaction rituals: low-risk participation opportunities, activities with sufficient time and challenge, and positioning of students as knowledgeable and capable
Saka et al. (2013)	Exploration of a new science teachers' participation in a school's community and how this influences his induction into the profession	The teachers of a midsized, public high school with a racially and ethnically diverse student population	Supporting development and learning of the school's students	A wide range of classroom- and school-oriented activities including faculty meetings, mandatory math "warm ups" in class, and informal conversations among teachers	Inconsistencies in individual teacher aspirations and school expectations shape the induction of a new teacher and lead to the teacher leaving the school

study highlights ways in which the two communities, which share some of the same goals, maintain unique repertoires of practice that can present constraints to collaboration. The article also addresses ways in which these community boundaries were traversed. Finally, Akerson and colleagues (2009) explore professional development to improve elementary teachers' understandings of and abilities to teach nature of science. Whereas the other articles cited here study existing COP, Akerson and colleagues create a COP to support their professional development goals.

Summary

Communities of practice offer a theoretical orientation for what it means to know and learn. The construct emerged through studies of learning communities not associated with schools and classrooms, but the idea offers important implications for how learning is situated within community contexts relevant for efforts to support teaching and learning in any context. In science education, there are numerous communities of practice, many of which are overlapping and mutually influential. Science education researchers apply the idea of communities of practice in varied contexts to illuminate how people know, do, and learn science.

Cross-References

- ▶ Activity Theory and Science Learning
- ▶ Agency and Knowledge
- ▶ Cultural Influences on Science Education
- ▶ Didactical Contract and the Teaching and Learning of Science
- ▶ Language and Learning Science
- ▶ Socio-Cultural Perspectives and Characteristics
- ▶ Socio-Cultural Perspectives on Learning Science

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Companion Meanings

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In science education, a central aim is that students learn scientific facts, models, and theories. In many countries they are also expected to learn the skills associated with the work of scientists and about science as a practice and a field of knowledge. So, in general, we can say that in science education students are supposed to acquire scientific knowledge, scientific skills, and knowledge about science.

Even when knowledge about science is not one of the objectives of a specific teaching activity, it could be argued that we cannot teach scientific knowledge without at the same time teaching about science, i.e., about the kind of knowledge and the kind of activities that are regarded as valid. In the same vein, we could say that it is not possible to teach students scientific concepts without communicating something about nature, e.g., what nature is, how it works, and so on. It is also obvious that when learning science, students also learn about themselves in relation to school science activities and perhaps also to science. All these extras in teaching and learning are known as "companion meanings."

The term "hidden curriculum" has sometimes been used to capture these extras. However, it is important to note that companion meanings are communicated and learned while learning science, i.e., companion meanings accompany scientific meanings. As such, companion meanings have a pivotal role in the learning of a worldview in science education and are a crucial component in the socialization content of science education.

The idea of companion meaning is based on the reminders of pragmatic philosophers that it is not possible to act in the world without involving choices and values. These values are sometimes visible in our actions, while at other times we follow norms without reflecting on them. In the latter case, we are not mindful of the values that guide our choices; we just do what we usually do.

As teachers we develop certain teaching habits, and in executing these habits, the values by which we choose the teaching content may be invisible to us. But it becomes obvious that we need to make value judgments when we realize that we cannot teach all the facts of science within, for example, the framework of compulsory education. Our values come into play every time we plan a lesson since we must include certain facts and exclude others for the simple reason that it is not possible to accommodate all the scientific claims about, say, energy in a single lesson. Thus, we have to grapple with the question of which fact or facts about energy are more worthy than others. Here it is important to recognize that this is not necessarily a relativist standpoint, but simply a plain recognition that actions inevitably involve some kind of value judgment.

When Wertsch introduced the term "privileging," we could say that he brought this insight into the heart of learning. Learning is not a mystery; it happens all the time. What is puzzling, though, is how or why learning takes one direction rather than another. Privileging facilitates one of a number of possible directions of learning and results in a specific learning outcome. In certain practices, specific privileging processes prevail, and in order to become part of a scientific practice, we have to learn specific habits of privileging. Since the privileging process is about choice, values are naturally involved.

We can make a crude distinction between ethical and epistemic values, where the former are often described as dealing with what is a good and correct way of, for example, treating human beings and nature. Epistemic values concern the practical values that are crucial for a specific activity, and it is those we are concerned with here because they build up companion meanings.

One of the major systematic changes that occurred during the scientific revolution that began in the seventeenth century was the separation of humans from nature to the extent that scientists became the observers and manipulators of the object "nature." Science required that nature be approached as an object, or thing, leading Thoreau and many others to criticize science for stripping nature of all its qualities. Regardless of whether or not we agree with that criticism, we have to learn to approach and talk about nature as a thing in order to learn and communicate science. For example, if we want to give the word "heat" scientific meaning, we cannot associate it with qualities that are connected to our bodily experience of feeling hot. Instead, we have to understand and use it in the context of a language game, where, for example, the word is given a meaning that is connected with the movement of things, i.e., atoms. The separation of nature from humans is one example of an intelligibility demand that we learn to practice as we learn science. Such demands are examples of companion meanings that we learn in the same time as we learn scientific concepts, models, theories, etc.

When we learn science, we also learn a new way of perceiving the world. Companion meanings play a crucial role in this learning because they help us to discern the things that really matter. When a biology teacher takes students to a forest, most of the students will see trees, while the teacher will also see connectedness. In order to perceive the forest in such a way, we need to master the practice of an intelligibility demand that is common in ecology, namely, that phenomena and events in nature are explained in relation to other phenomena and events.

Aesthetic expressions of likes and dislikes can also function as epistemic values and be crucial for the privileging process. Aesthetic values such as elegance are sometimes used in the privileging process in a laboratory: the fewer tests we use in order to reach the right results, the more elegant the experiment becomes. In this sense, learning science is akin to learning specific aesthetics. This becomes obvious if we look at the history of science. For example, biologists have long been dependent on artists' representational aesthetics, i.e., making perfect representational drawings of animals and plants, for a valid science.

In science education, there is an almost constant production of companion meanings concerning what counts as valid or invalid knowledge and what counts as proper ways of proceeding in investigations in order to produce valid knowledge. These companion meanings concern what we sometimes call the view of science or the epistemological dimension of an activity. It is important to note that these companion meanings are learned, as the intelligibility demands, at the same time as we learn science. Companion meanings are sometimes reflected on by students, although more often than not students just learn to practice them. It is also important to note that the practice is learned in the context of school science and not in the context of science. Thus, the epistemology students learn is situated in the school science activities. Much of the learning revolves around learning how to discern between valid or invalid knowledge and ways of producing knowledge in school science. Many of the questions that students ask teachers, and a lot of teachers' communications, relate to this discernment. For example, nodding or other encouraging actions often confirm that the activity that a student has staged is valid in order to, for example, generate a correct answer to a question (Lidar et al. 2006). This learning of a practical and situated epistemology can be an important part of the learning of a view of school science and of science.

The learning of companion meanings and the learning of a specific way of privileging in the meaning-making process occur in the same time. Thus, when we have learned a practical and situated epistemology, i.e., a practical epistemology (Wickman and Östman 2002), we have acquired a specific perception and a specific manner of producing meaning and knowledge.

When creating meaning and when learning, we cannot avoid creating a relation to the practice we are experiencing. Thus, the learning of science often involves an identification process. For example, we might learn that we are very successful or unsuccessful in relation to the ongoing learning process or that for one reason or another we are not cut out to be scientists. The identification process is often connected to the companion meanings that are communicated in science education, for example, the gender bias that accompanies a dominance of pictures of males in text books.

As companion meanings have a crucial role to play in the privileging process, paying attention to companion meanings can enhance educators' control of the learning process and thereby make the transition from everyday discourse to a scientific discourse as smooth as possible for the students.

Another benefit of paying attention to companion meanings is that it makes us better equipped to deal with crucial questions about worldviews, citizenship, identity, and scientific literacy in science education (Östman and Almqvist 2011). Worldviews do not only consist of things like conscious values and commitment, but also our way of practically perceiving and approaching nature, our fellow beings, truth, arguments, etc. Companion meanings are epistemic values that concern the latter. Moreover, there is plenty of historical evidence to show that epistemic values can be questioned and criticized from an ethical perspective. The criticism of Thoreau and others during the Romantic period is one example of this. Many biology teachers have also experienced that the practice of dissecting can no longer only be judged from an epistemic point of view, but must also include ethical values.

One way of furthering the benefits of companion meanings is to create typologies of the different types of content that make up science education. For example, the Curriculum emphases typology (Roberts 1998) highlights companion meanings about science, the Nature languages typology highlights the intelligibility demands regarding nature, and the Subject focus typology concerns companion meanings about the relationship between human beings and nature that is learned in conjunction with science (Östman 1998).

Cross-References

- ▶ Bildung
- ▶ Curriculum Emphasis
- ▶ Epistemic Goals
- ▶ Values
- ▶ Values and Western Science Knowledge

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Competence in Science

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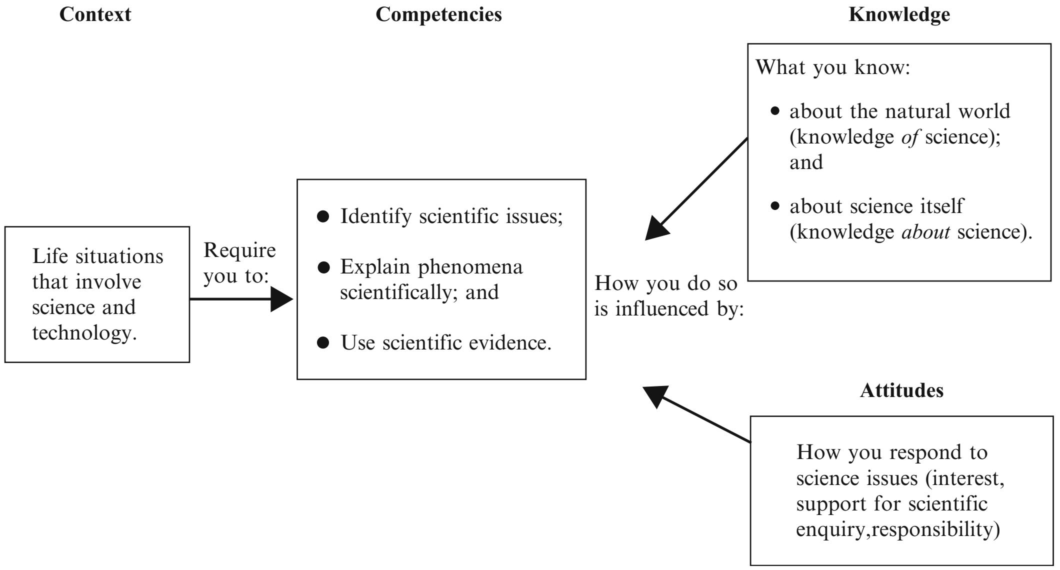
It is an international trend that national curricula and descriptions of expected learning outcomes from schooling are increasingly framed in competence terms, rather than in knowledge and skills to be learned. Competence in this usage refers to a certain "capacity" or "potential" for acting efficiently in a given context. The idea of competence has come into the educational sphere from the business community and society in general. Both business life and vocational training have for many years operated with job competence as something that reflects the expectations of workplace performance, the ability to accomplish a particular task. Also, in a globalized world, educational goals are increasingly being formulated across nations via global institutions such as the United Nations/UNESCO (e.g., "Education for all"), the OECD, and the European Union (e.g., "Lifelong learning") in order to capture some overall strategic aims. In this respect the introduction of competence into the educational world reflects the role of schools as providing a general socialization and preparation for life, rather than only specific knowledge.

The reasons for the concept of competence having such a huge impact on education, despite its origins in the economic sphere, are manifold. Generally speaking, the impact of competence reflects the need for a concept to capture the complexity of demands placed on the individual person by modernity and post modernity in a time of diminishing social and cultural cohesion. This goes together with changing views on learning and teaching, from behavioristic approaches based on the transfer of canonical knowledge to constructivist ways of creating meaningful understanding through acting in authentic situations. This, in turn, is consistent with other factors influencing education such as the amount of factual knowledge growing in



such an uncontrollably rapid fashion that education must shift focus to methods of knowledge acquisition and general practice within a subject, instead of selecting and transferring often quite randomized knowledge.

Due to its widespread and varying usage, competence is not an easy concept to capture. As Weinert (2001) expresses it: *There is no basis for a theoretically grounded definition or classification from the seemingly endless inventory of the ways the term competence is used. . . . There (is) . . . no single common conceptual framework.* Competence can be seen as an extension of the former goal category "qualification," based on knowledge and skills, by adding to this the ability and willingness to use the knowledge and skills in complex situations. Fulfilling complex demands and tasks requires not only knowledge and skills but also involves strategies and routines needed to apply the knowledge and skills, as well as appropriate emotions and attitudes, and effective management of these components. Thus, the notion of competence encompasses cognitive but also motivational, ethical, social, and behavioral components. It combines proficiency and intentionality into a capability to solve tasks and problems of some complexity.

The most authoritative, international definition is probably from OECD's DeSeCo project:

> A competence is defined as the ability to successfully meet complex demands in a particular context through the mobilization of psychosocial prerequisites (including both cognitive and non-cognitive aspects). This represents a demand-oriented or functional approach to defining competencies. The primary focus is on the results the individual achieves through an action, choice, or way of behaving, with respect to the demands, for instance, related to a particular professional position, social role, or personal project. (Rychen and Salganik 2003, p. 43)

The term competence is very often seen as interchangeable with competency, without any consistency in this interchangeability. Some will argue that "competence" is mainly referring to the concept as such (e.g., competence assessment problems), while "competency" is used referring to a specific ability (e.g., the competency to model in physics) but usage is inconsistent. The use of the plural "competencies" seems more widespread.

Competencies can be defined within the area of personal development (e.g., creative or innovative competence) and social behavior (e.g., teamwork competence) as well as within academic, subject-specific areas, like science. To become effective, science competencies require integration with personal and social competencies. For example, to design or to use models in science requires creativity and a certain level of affective involvement to enable one to overcome disappointments and criticism; further, working in groups and communicating the results requires social competencies.

Science competence can be attributed to a narrow part of science such as a part of a discipline or to a wider aspect of science performance, such as the ability to model. Used in the wider sense, science competence is closely linked to the concept of science literacy, where the construct of scientific literacy can be defined in terms of a set of competencies that a scientifically literate individual would be expected to display. This is for instance seen in the PISA 2006 Science Framework (OECD 2006), shown in the figure immediately below. In this framework scientific literacy is defined as the ability to use scientific knowledge and processes not only to understand the natural world but also to participate in decisions that affect the natural world; here the competencies are the specific processes that are seen as characteristic of science.

In other competence formulations of science, competence is seen as an integration of the processes and the knowledge and the attitudes in a practice – performed within relevant contexts. Many European countries have implemented competence models in science. For example, the Danish science competencies, used across all educational levels, are an attempt to capture what it is to do science, independent of the specific discipline or content. The Danish educational system operates with four core science competencies:

- An empirical, experimental competence (i.e., the ability to measure and to perform experiments and do fieldwork, to go into clinch with reality)
- A modeling competence (i.e., the ability to develop, use, and analyze models)
- A representational competence (i.e., the ability to describe and present knowledge using different modalities and formats and to transform between different representations of the same phenomenon)
- A putting-into-perspective competence (the ability to put science into cross-curricular, historical, philosophical, and personal perspectives, a “bildung” dimension).

These science competencies are described specifically in the different science domains/subjects together with general competencies like communication, argumentation, asking questions, etc. which are common for all subjects.

Teaching for competence is different to other science teaching. Conventionally a teacher will ask: “What must the pupils know?” – and will then plan what the students need to do in order to achieve this. In competence-directed teaching, the teacher will ask: “What must the students be able to do?” – and will then consider what they must know to be able to do this. The knowledge is subordinate to the actions and the situations the students are expected to control. The different elements necessary for performing the task are learned in coherence in a whole task approach in a realistic situation. It could typically be in a project-oriented sequence where the students learn actively and organize the learning processes themselves, with the support of the teacher.

Correspondingly, assessing science competence is different from assessing knowledge and skills. The more complex the learning goals, the more difficult they are to measure. The understanding of competences as the ability to cope with relatively complex challenges in an adequate way means that assessment methods necessarily have to be relatively advanced, flexible, and process oriented. And, at the very least, they have to be valid. Thus, artificial tasks such as multiple-choice test items that might test simple skills or knowledge recall can hardly measure competencies. For validity reasons competence assessment should be able to examine how students perform while going through the processes that constitute the competence to be assessed. Coincident with this, the assessment of a multifaceted concept like competence should be based on a competence model with multiple dimensions, and some clear criteria and some levels of performance should be described to establish a progression for scoring and for formative feedback reasons. The assessment also has to take place in real world or authentic situations to which the competence can be ascribed. For reliability reasons some kind of standardization should be applied to the expected activities. All these conditions are not easy to fulfill. At the one extreme students are observed in their everyday setting solving problems and tasks during a considerable time span, and the overall impression is judged. This is a costly method with high validity but often to the disregard of reliability and generalizability. At the other extreme students are placed in a room with paper and pencil to tick boxes and write short answers within a short time limit. With this relatively cheap method you can achieve high reliability, but this is clearly at the expense of validity. Irrespective of approach it is the nature of the test assignment (or the items) and the test situation that determines whether it is reasonable to consider the test a competence test. Especially for large-scale competence assessment, there is a risk that what is assessed is more isolated skills and detached knowledge than competence in the proper sense.

Cross-References

- ▶ Argumentation
- ▶ Assessment of Doing Science
- ▶ Bildung
- ▶ Companion Meanings
- ▶ Problem Solving in Science Learning

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Computer-Based Assessment

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Keywords

Computer based; Digital; Innovative; Next generation; Technology based; Testing

The next generation of assessments in science and other domains is taking advantage of technologies to transform what, how, when, where, and why testing occurs (Quellmalz and Pellegrino 2009). The capabilities of technologies are being harnessed to support assessment of the kinds of complex science understandings and practices advocated in the *Framework for K-12 Science Education* and the *Next Generation Science Standards*. These documents, along with other national and international science frameworks and standards, advocate teaching and testing of deeper learning about systems in natural and designed worlds integrated with application of the practices used by scientists and engineers to study and design these systems. Assessments of the *Next Generation Science Standards* will require dynamic, richer, and more extended and complex representations of science phenomena along with ways for students to actively investigate and modify the interactions among system components and emergent system behaviors. Forms of computer-based assessment are migrating from delivery on computers to other devices such as tablets, handheld devices, and tools not yet imagined. The increased mobility of assessment instruments permits greater flexibility for where and when evidence of learning can be gathered. Significantly, technology-enhanced assessments can blur the distinctions between assessments *of* and *for* learning.

Computer-Based Testing in Large-Scale Assessments

Initial forays into computer-based testing came from large-scale assessment programs administered by states, nations, and major testing companies. Economics and logistics were the primary factors that drove the search for efficiencies of assessment functions such as test development, delivery, adaptation, scoring, and reporting. Authoring shells and item banks aligned to content standards enable efficient development and assembly of items into comparable test forms. Online administration eliminates costs for shipping, tracking, and collecting print booklets yet simultaneously introduces other challenges related to computer access, server limitations, and security. Computer scoring provides rapid return of results and generation of reports tailored to multiple audiences. Flexible administration times and locales can shift annual, on-demand testing to interim, curriculum-embedded, and just-in-time challenges.

Large-scale computer-based testing now occurs in numerous international, national, and state assessment programs. In many of these programs, technologies are used not just to support testing logistics, but to also design innovative tasks and items that aim to measure understanding of dynamic science system interactions and the kinds of science inquiry practices not well measured by the traditional multiple-choice item format. In 2006, the Programme for International Student Assessment (PISA) began piloting computer-based science assessments and in 2015 will administer simulation-based science tasks. Similarly, the 2009 National Assessment of Educational Progress (NAEP) of science fielded interactive computer tasks to better assess science inquiry and will continue to administer these interactive investigations. The 2014 NAEP for Technology and Engineering Literacy will be delivered entirely online and include long and short scenario-based tasks to assess crosscutting practices for understanding technological principles, for developing solutions and achieving goals, and for communicating and collaborating. The state assessment consortia developing tests for common core math and literacy standards will be computer delivered and scored. One of the consortia will employ computer-based adaptive testing. It is likely that similar state consortia will be formed to develop new assessments for the *Next Generation Science Standards*. The next-generation assessments for science will be able to take advantage of advances in the use of simulations and games for promoting science learning to design innovative, interactive technology-enhanced science assessments (NRC 2011).

Technology Supports for Science Assessment

The rapidly advancing capabilities of digital and networking technologies are changing the ways that science assessments are developed, administered, and scored. These expanded logistical functions, in turn, will permit the design of richer, deeper, more interactive, and extended assessments that can measure coherent science knowledge and practices.

Technology-Based Assessment Infrastructures. Technologies support assessment functions related to authoring, delivering, collecting, and reporting measures of learning so that they are more efficient and economical. Technology can also assist the development and recording of alignments of the learning and assessment targets in state, district, and classroom science programs with the broader *Next Generation Science Standards*. Item banks and digital, multimedia collections of performance assessment tasks and products can be created and searched by the standards they test.

Technologies can expand the range of science and engineering design knowledge and strategies that can be tested. Not only can the core disciplinary ideas, crosscutting concepts, and science and engineering practices in the *Next Generation Science Standards* be assessed in real-world contexts and problems, but evidence of hard-to-test crosscutting practices such as scientific literacy, use of the “tools of the trade,” collaboration, and communication can be collected. For example, Twenty-first-century skills for finding and using resources and for collaborative problem-solving can be more easily observed and recorded when the information searches, collaboration, and communications occur online. By permitting access to online resources and expertise, technologies can at the same time record those searches and assess them. Digital records of collaborations with virtual and real peers and experts can be tracked and evaluated. Summative tasks can be designed to provide specified science resources and virtual peers and experts. For performance assessments, planned assessment probes and tasks can be unobtrusively inserted by technology into activities and automatically scored or stored for rubric-based evaluations by teachers and students. Online training for reliable use of the rubrics by students and teachers can establish and document rater reliability. Electronic notebooks and portfolios can collect student work in multiple static and dynamic modalities, including samples of designs and work in progress as well as scans and video of final artifacts and performances. Customized reports of assessments and evaluations of interim work and artifacts and performances by individuals and teams can be analyzed, summarized, and reported to multiple audiences. For example, collections of engineered solutions and the records of their designs and iterative tryouts can support assessments of effective engineering design practices.

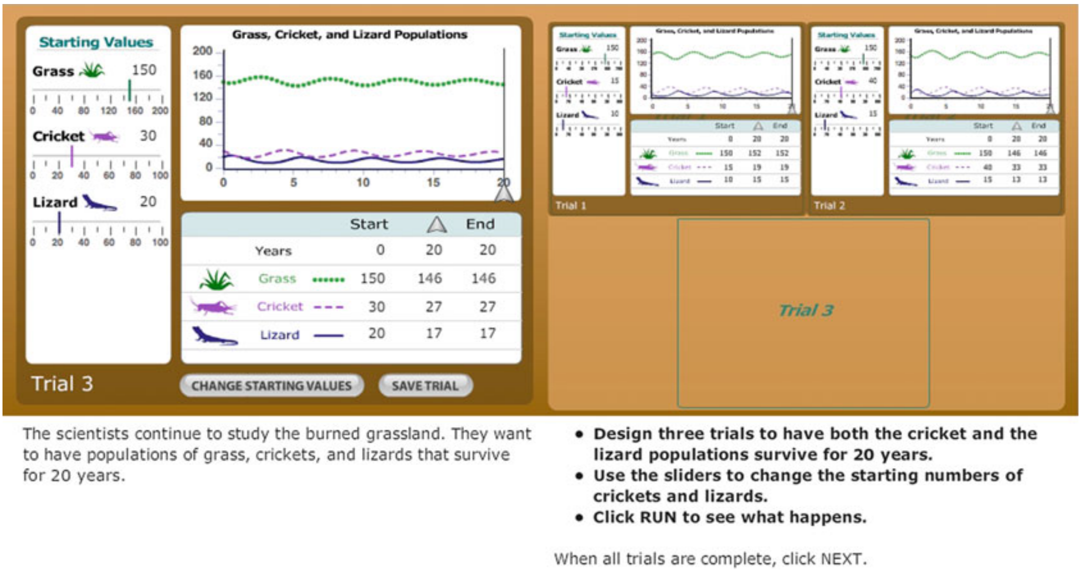
Innovative Technology-Enhanced Assessment Task Designs. Once the disciplinary core ideas, crosscutting concepts, and science and engineering practices to be tested have been specified, plans can be laid for collecting observations of learning to serve formative purposes during instruction and to serve summative interpretations of achievement. Technology-based formative assessments could be blended into hands-on and digital tasks during classroom-based science and engineering projects. Designs of assessments for summative judgments of learning would involve gathering evidence from final solutions and performances. Some of the component knowledge and practices involved in final performances or solutions could be responses to explicit tasks and questions that could be scored by the system automatically. Rubrics could guide evaluations of the complex performances.

A major technological advance is the capacity for representing dynamic natural and man-made systems "in action" and for making visible the invisible system interactions that are otherwise too fast, slow, big, small, or dangerous. Simulations can support student interactions with these dynamic displays to scaffold understanding and active investigations of how components interact to produce emergent system properties. Engineering projects can prepare alternative designs, tryout digital mockups and prototypes, run simulations to predict outcomes, and iteratively troubleshoot.

Technologies can support designs of innovative assessment tasks that will elicit observations of progressions of science learning (Quellmalz et al. 2012a). Technology-based interactive tasks can not only monitor learning, but also respond to student input with just-in-time feedback and coaching. These interactive, technology-based tasks can be designed using simulations, virtual immersive environments, and games.

Research on the benefits of system models and simulations for science teaching and assessment can offer guidelines for development of interactive science and engineering assessments (NRC 2011). Simulations can present models of natural and designed systems and their key components, interactions, and resulting system behavior. Simulation-based assessment tasks can be embedded within authentic, significant, recurring problems in the science and engineering domains. Computer-based modeling tools can allow students to see and iteratively test interactions among structural components of a system across time, scale, and levels. Student problem-solving and inquiry processes can be logged and assessed.

For example, the SimScientists Assessment System is developing suites of simulation-based formative and summative assessments for middle school science units (Quellmalz et al. 2012a; http://simscientists.org). Figure 1 shows a screenshot of an excerpt from an end-of-unit benchmark assessment that tests students' inquiry skills. The screenshot is from an assessment scenario set in an Australian grassland. The overarching problem is that the ecosystem needs to be restored after a wild fire. In the first part of the scenario-based assessment,



Trial 3

	Start	△	End
Years	0	20	20
Grass ••••••	150	146	146
Cricket - - -	30	27	27
Lizard ——	20	17	17

Trial 1 (Starting Values: Grass 150, Cricket 15, Lizard 10)

	Start	△	End
Years	0	20	20
Grass	150	152	152
Cricket	15	19	19
Lizard	10	15	15

Trial 2 (Starting Values: Grass 150, Cricket 40, Lizard 15)

	Start	△	End
Years	0	20	20
Grass	150	146	146
Cricket	40	33	33
Lizard	15	13	13

The scientists continue to study the burned grassland. They want to have populations of grass, crickets, and lizards that survive for 20 years.

- **Design three trials to have both the cricket and the lizard populations survive for 20 years.**
- **Use the sliders to change the starting numbers of crickets and lizards.**
- **Click RUN to see what happens.**

When all trials are complete, click NEXT.

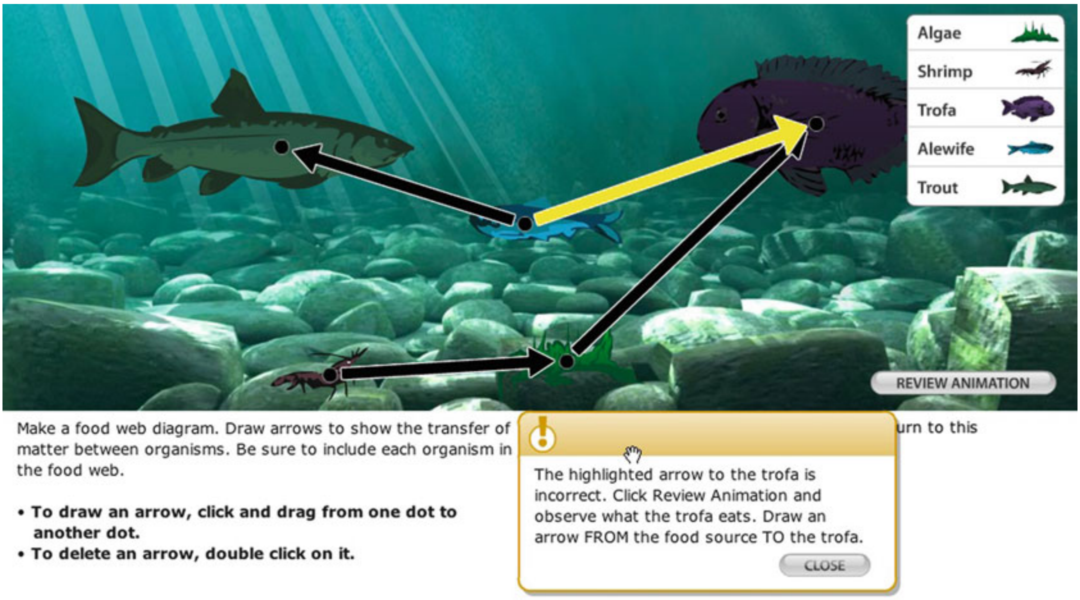
Computer-Based Assessment, Fig. 1 Screenshot of SimScientists Ecosystem benchmark assessment to test use of simulations to investigate effects of changing population sizes

students observe the interactions of the organisms to create a food web representing the flow of energy and matter through the system. In the Fig. 1 screenshot, students' inquiry skills are assessed for using a simulation to conduct three investigations of what different numbers of organism populations would survive in a balanced ecosystem.

An important benefit of such technology-based interactive assessment tasks is that they can provide students with opportunities to use some scientific "tools of the trade." These might include manipulations of models and simulations for science and engineering tasks or use of computer design systems for an engineering task. Digital tools can allow students to find, organize, and analyze data and represent findings in multiple formats such as visualizations, graphs, tables, and models. Mobile devices can allow students to collect, store, and retrieve a range of observations and data in settings beyond the classroom. Presentation software can allow students to share designs, models of work in progress, and findings and solutions. Each of these tools of the trade can provide evidence of learning as they are being used.

Technology Supports for Classroom Science Assessment

Classroom-based science assessments can also take advantage of a range of technology affordances. One genre of computer-based classroom products mimics the item formats in state tests, thereby limiting the types of science knowledge and inquiry strategies that are and can be tested. Simulations, virtual immersive environments, and games are being developed to present dynamic, interactive representations of science systems and to integrate feedback and hints that can serve as formative assessments to benefit learning. For example, the SimScientists Assessment System is developing suites of simulation-based assessments to be embedded within middle school instructional units. The assessments are intended for formative purposes – to provide feedback and additional scaffolding to reinforce learning and to generate reports of learning progress. The simulation-based assessments are designed to measure assessment targets for understanding the components, interactions, and emergent behavior represented in models of science systems and also to assess inquiry practices



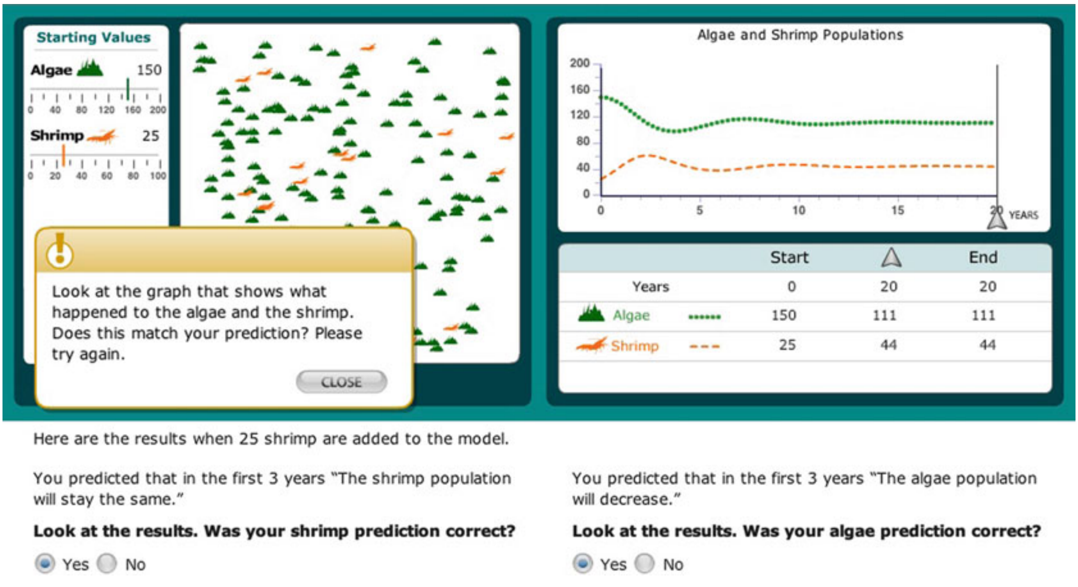
Make a food web diagram. Draw arrows to show the transfer of matter between organisms. Be sure to include each organism in the food web.

- **To draw an arrow, click and drag from one dot to another dot.**
- **To delete an arrow, double click on it.**

urn to this

The highlighted arrow to the trofa is incorrect. Click Review Animation and observe what the trofa eats. Draw an arrow FROM the food source TO the trofa.

Computer-Based Assessment, Fig. 2 SimScientists screenshot of ecosystems formative assessment with feedback and mid-level coaching for drawing a food web



Look at the graph that shows what happened to the algae and the shrimp. Does this match your prediction? Please try again.

		Start		End
Years		0	20	20
Algae	••••••	150	111	111
Shrimp	- - -	25	44	44

Here are the results when 25 shrimp are added to the model.

You predicted that in the first 3 years "The shrimp population will stay the same."

Look at the results. Was your shrimp prediction correct?

● Yes ○ No

You predicted that in the first 3 years "The algae population will decrease."

Look at the results. Was your algae prediction correct?

● Yes ○ No

Computer-Based Assessment, Fig. 3 Screenshot of population dynamics inquiry task with coaching

for investigating the science systems. Figures 3 show ecosystems embedded assessments within the context of a remote mountain lake. When students are asked to draw a food web diagram in the embedded assessments, they are provided with graduated feedback and coaching that helps them complete the task before they can continue. Figure 2 shows the mid-level coaching students receive if they have not completed the task successfully on the second try. Students are coached to review the animation to observe the interactions between the organisms in order to correctly draw the arrow to depict the flow of energy from the energy source to the consumer.

Figure 3 shows a screenshot of a SimScientists Ecosystem curriculum-embedded assessment task for the science inquiry practice of using a simulation to predict, observe, and explain changes in the ecosystem. The embedded assessment is designed as a formative assessment that provides individualized feedback, graduated coaching, and a report of progress on the assessment targets.

When aligned with interactive summative assessments, curriculum-embedded simulation-based science assessments can become powerful components of a balanced state science assessment system (Quellmalz, et al. 2012b). Computer-based testing is rapidly evolving to support assessments of richer, deeper, interactive collaborative science learning. The capabilities of technologies will enable next-generation assessments to represent next-generation science learning.

Cross-References

- ▶ Computers as Learning Partners: Knowledge Integration
- ▶ Engineering and Technology: Assessing Understanding of Similarities and Differences Between Them

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Computers as Learning Partners: Knowledge Integration

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Keywords

Argumentation; Assessment; Computers; Inquiry; Knowledge integration

Introduction

The Computer as Learning Partner (CLP) project, funded by the National Science Foundation, has leveraged new technologies to strengthen inquiry activities and improve science learning in a research program involving a partnership of learning scientists, classroom teachers, discipline experts, technologists, and designers. CLP started by researching how Apple II computers with temperature-sensitive probes that generate dynamic, real-time graphs could serve as classroom *laboratory partners*. Later, taking

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advantage of the Internet, the partners designed the Web-based Inquiry Science Environment (WISE) as a *learning partner* to guide students as well as tools for teachers to monitor student progress, flag student work for class discussion, and provide feedback, making WISE a *teaching partner*. Recently, the partners have developed ways to analyze student work and provide adaptive guidance as students grapple with complex scientific ideas that allow the computer (via the WISE environment) to serve as an *inquiry partner*.

CLP classroom research involves longitudinal, comparison, and case studies that have been synthesized in the *knowledge integration framework*. The framework takes advantage of the multiple ideas students encounter and develop about each science topic. For example, when asked to predict the temperature of objects in their room, students make a wide variety of comments, like (a) metal objects are colder than wooden objects based on how they feel; (b) each object has its own temperature, like rabbits and humans; (c) objects come to the same temperature; (d) objects never come to the same temperature; (e) metal objects contain cold that can be used to keep people cool; and (f) objects get their temperature from the sun. CLP research revealed that a lecture on thermal equilibrium, telling students that all the objects (except those with their own heat source) are the same temperature, had little impact. Some students added this idea to their repertoire, but did not use it exclusively. Even when students used the temperature-sensitive probes to measure the temperature of the objects in the room, some asserted that the probes were “broken” because they showed that metal and wood objects were the same temperature! The CLP partnership designed instruction to help students build on their prior reasoning (e.g., that metals impart cold) to help them consider new evidence, construct better arguments, and articulate a coherent account of thermal equilibrium (Linn and Hsi 2000).

CLP research has focused on two main questions about knowledge integration. First, how can science instruction take advantage of visualizations and virtual experiments to design representations for new ideas that, when added to the repertoire of ideas, promote coherent accounts of science? Second, what forms of computer and teacher guidance encourage students to refine their reasoning strategies so that they can distinguish among their repertoire of ideas, increase the coherence of their ideas, and develop lifelong learning capabilities? For two decades, CLP has addressed these questions by experimenting with new technologies, refining curriculum materials, and identifying instructional principles and patterns that promote knowledge integration (Linn and Eylon 2011; Slotta and Linn 2009).

The curricular units developed by the CLP research program promote knowledge integration by engaging students in actively making sense of the evidence they encounter and iteratively improving the coherence of their arguments. Often, science instruction tells students accurate information and expects them to recall it in the future. But when new ideas are not integrated, students either forget them or conclude that they are appropriate for classroom activities but not everyday life. For example, one student remarked that objects in motion remain in motion in the classroom, but they come to rest on the playground!

Computer as Laboratory Partner

As a laboratory partner, CLP took advantage of temperature-sensitive probes that generated graphs as liquids cooled or were heated. These graphs helped to make ideas about thermodynamics visible to students. An unanticipated consequence was that watching data collection in real time also helped students understand the nature of graphs. When students used probes rather than recording data manually, they were more likely to accurately interpret a graph of a bicyclist going down a hill [speeding up] and then going up another hill [slowing down] rather than seeing the graph as an actual picture of a hill.

CLP recognized the importance of helping students to integrate their ideas. For thermodynamics, studies showed that students integrated more of their ideas when instruction featured an accessible "heat flow" model rather than a model based on molecular kinetic theory. A simulation, where students could conduct virtual experiments to determine the rate of heat flow in varied materials surprised many students, who initially thought that heat flowed at the same rate in all materials. This visualization also helped students interpret their sensory experiences, when touching metal and wood objects in hot and cold environments. They could develop the notion that they were detecting the rate of heat flow between their hand and the object, realizing that metals were better conductors than wood, and comparing the temperature of their hand relative to that of the object. The teacher, in the CLP classroom, asked his students to compare how metal and wood objects feel on a hot day at the beach and on a cold day in the mountains. CLP labeled ideas that promoted integrated understanding pivotal cases. Pivotal cases feature controlled experiments (such as comparing materials in hot and cold contexts), illustrate situations that are likely to reoccur in the lives of students, stimulate discussion among students by supporting narrative accounts of experiences, and connect multiple scientific principles (such as connecting insulation and conduction to thermal equilibrium).

CLP conducted a longitudinal study that led to four principles that guide the design of new curricular activities and materials (Linn and Hsi 2000):

Make science accessible – calls for encouraging students to connect new knowledge to preexisting knowledge and appreciate the relevance of science to their lives. In CLP, students connected their investigations of thermodynamics to personal experiences, like packing lunches so that food stays hot or cold.

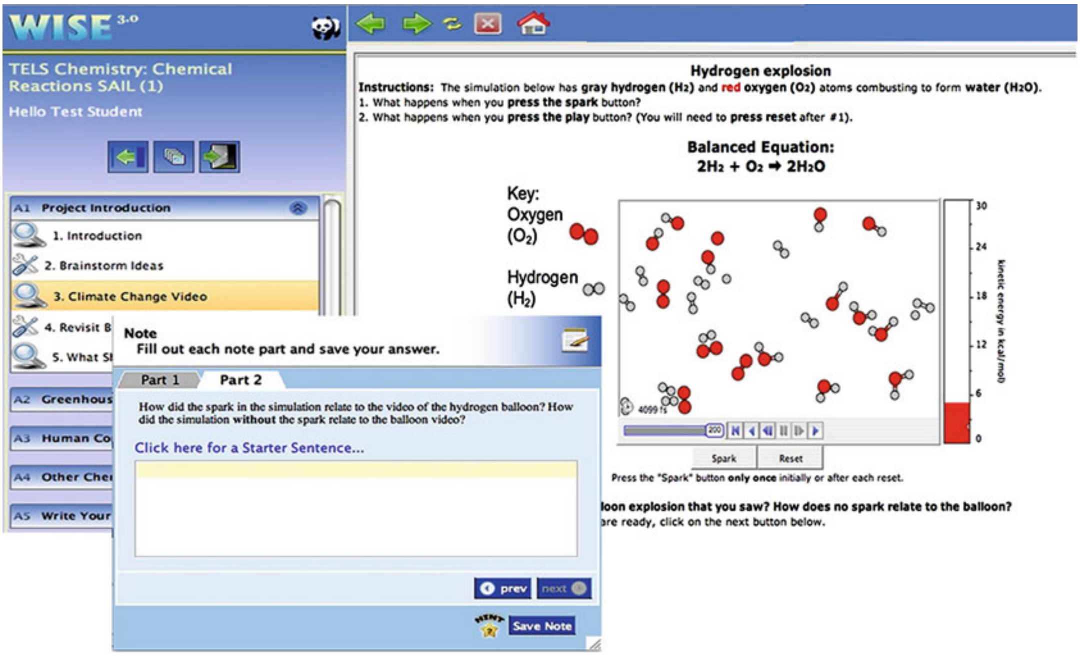
Make thinking visible – refers to both the process of modeling how ideas are connected and organized in normative understanding and the process of students articulating their own ideas to help teachers monitor progress. In CLP, our use of visualizations, pivotal cases, and real-time data collection with probes all served to make thinking visible.

Help students learn from others – calls for negotiating ideas with others, in order to jointly explain complex ideas. To achieve this in CLP, students worked in pairs to interpret their experiences. Often they appropriated ideas from their partner to advance their understanding.

Promote autonomy and lifelong learning – involves helping students monitor their progress and reflect on their ideas. To achieve this in CLP, students were guided by an inquiry cycle, reflected on their ideas in short essays, and explained their ideas to others in classroom debates. Thus, when students articulated their ideas, they benefitted in two ways. First, they reconsidered and often reorganized their ideas. Second, they made their ideas visible for others.

Computer as Learning Partner

Powerful classroom computers and Internet connectivity enabled the development of the Web-based Inquiry Science Environment (WISE) to further explore the computer as a learning partner. WISE logged in students and captured records of their inquiry activities, linking to embedded assessments and virtual experiments using an inquiry map (see Fig. 1). Using WISE, the research partnership could design comparison studies where students conducted different activities within the same classroom. Comparison studies revealed difficulties students had interpreting visualizations or conducting virtual experiments and supported our investigation of promising instructional sequences (Slotta and Linn 2009). A wide range of comparison studies included embedded and end-of-unit knowledge integration items that were scored using a rubric that emphasized the use of evidence to build an argument. Students generate short essays, concept maps, virtual experiments, and drawings, as well as annotations of scientific materials such as microscope slides to document their reasoning. These assessments



Hydrogen explosion

Instructions: The simulation below has **gray hydrogen (H_2)** and **red oxygen (O_2)** atoms combusting to form **water (H_2O)**.
1. What happens when you **press the spark** button?
2. What happens when you **press the play** button? (You will need to **press reset** after #1).

Balanced Equation:
$2H_2 + O_2 \rightarrow 2H_2O$

Press the "Spark" button **only once** initially or after each reset.

loon explosion that you saw? How does no spark relate to the balloon?
are ready, click on the next button below.

Note
Fill out each note part and save your answer.

How did the spark in the simulation relate to the video of the hydrogen balloon? How did the simulation **without** the spark relate to the balloon video?

Click here for a Starter Sentence...

Computers as Learning Partners: Knowledge Integration, Fig. 1 Screenshot of chemical reactions unit in WISE

contribute to learning by asking students to make sense of their ideas and explain them to others.

For example, in the *WISE Photosynthesis* unit, students explore how light energy is transformed into chemical energy and is stored as glucose, but have difficulty distinguishing among their views that energy from the sun is "used up," "disappears," and "gets stored in the chloroplast." Experiments comparing static and dynamic representations of photosynthesis and cellular respiration demonstrated that dynamic representations were better at promoting knowledge integration (Ryoo and Linn 2012).

In performing the *WISE Chemical Reactions* unit, students have multiple ideas about what happens between one side of the equation and the other. They often believe that "there are no intermediate states," that "all the molecules break into atoms and recombine," and that "extra atoms disappear." When students make drawings of the initial, final, and intermediate states of the reaction (i.e., to articulate their predictions) and interpret the visualization (Fig. 1), they gained a more integrated understanding than those who just conducted additional virtual experiments (Linn and Eylon 2011).

WISE researchers synthesized a knowledge integration instructional pattern, combining the comparisons studies and related research (Linn and Eylon 2011). The pattern has four processes:

Making predictions. When students make predictions before encountering new ideas, they articulate their repertoire of ideas. Asking for predictions acknowledges the individual backgrounds and experiences that students have and enables designers and teachers to appreciate the diverse ideas students bring to science class. By testing their predictions, students are guided to interpret the results of their investigations in light of their own ideas.

Adding ideas. The knowledge integration pattern calls for adding pivotal cases that students find accessible. It incorporates research showing that dynamic, interactive visualizations only succeed when combined with other knowledge integration processes including making predictions and distinguishing ideas.

Distinguishing ideas. WISE researchers found that students need to distinguish new ideas from existing ideas within their repertoire to fully integrate their understandings. For example, when students were asked to fill in four boxes to draw how a chemical reaction progresses, they tended to revisit the visualization to test their conjectures and add more normative ideas. Those who only conducted more experiments also watched the visualization additional times but did not pay attention to elements, such as lone atoms, that eventually were combined into molecules.

Reflecting. When prompted to reflect after encountering new ideas, students explain their reasoning and construct knowledge – both well-documented strategies for increasing learning outcomes. When combined with activities that support students' distinguishing among ideas, prompts for reflection and explanation ensure that students reconsider nonnormative ideas.

WISE investigations led to a set of design principles to help teachers and curriculum designers take advantage of the knowledge integration processes (Kali et al. 2008). For example, one principle calls for encouraging students to critique flawed experiments that require them to distinguish among ideas in their repertoire.

Computer as Teaching Partner

Embedded assessments can provide formative evaluation of student learning that also helps teachers refine their practice. In a busy classroom using computer-based materials, it is hard for a teacher to distinguish between a student who is learning intently by exploring a model or experiment and one who is just going through the motions or is confused. As materials become more sophisticated, it is increasingly difficult for teachers to play an active role in planning their delivery or enacting instruction within the classroom. WISE developed tools for teachers such as "flag student work" so they could monitor classroom activities and review student work to plan their next lesson.

The knowledge integration framework is also valuable for designing professional development programs to improve use of technology-enhanced materials. When teachers used the knowledge integration framework and evidence from student work to revise their instruction during a summer workshop, they were able to improve student outcomes the following year. A review revealed that, in general, when programs engaged teachers in the knowledge integration processes of making predictions about the effectiveness of instruction, introducing new ideas as pivotal cases, reviewing student work to distinguish among alternative teaching practices, and reflecting on their plans to implement the unit in the following year, they were more successful than programs lacking these elements (Gerard et al. 2011).

Computer as Inquiry Partner

WISE is taking advantage of new technologies such as natural language processing to explore how automated guidance, when added to proven online inquiry units, can augment teacher effectiveness and encourage students to integrate their ideas. By diagnosing the student's knowledge integration level within a reflection or other assessment, encouraging the student to revisit relevant visualizations or conduct a new activity, and asking the student to regenerate their argument, automated guidance can help students distinguish among their ideas. Comparison studies suggest that knowledge integration guidance is more effective than either specific guidance (identifying inaccurate ideas) or general encouragement (e.g., to add more evidence) for helping students build coherent understanding.

The CLP and WISE research programs have identified promising ways to ensure that all learners can succeed at science inquiry. Designing powerful pivotal cases that take advantage of visualizations and guiding students with the knowledge integration patterns have the potential to prepare scientifically literate citizens. The knowledge integration framework offers designers principles and patterns that can improve assessment, curriculum materials, instruction, and professional development.

Cross-References

- ▶ Argumentation
- ▶ Inquiry, as a Curriculum Strand
- ▶ Inquiry, Learning Through

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Concept Mapping

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Keywords

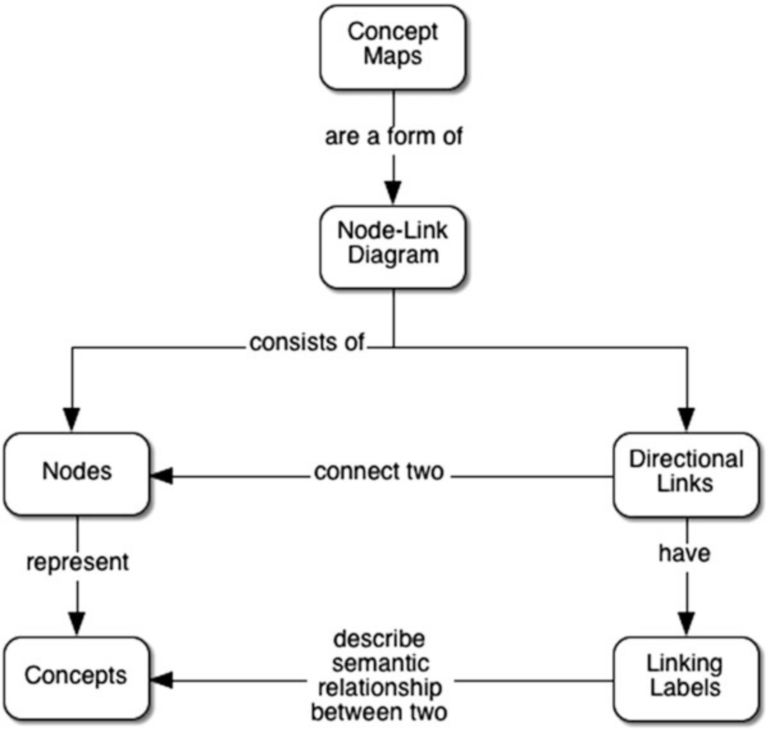
Graphic organizer; Knowledge map; Knowledge visualization

Definition

From the perspective adopted in this entry, a concept map is a node-link diagram showing the semantic relationships among concepts, where the process of constructing concept maps is known as "concept mapping." A concept map consists of nodes (concepts), arrows as directional links, and usually captions for each link that describe the relationship between nodes [see Fig. 1]. Concepts can be described as perceived regularities or patterns of events or objects, or records of events or objects. Two concepts connected with a labeled arrow can be described as a proposition. Concept maps are versatile graphic organizers that can represent many different forms of relationships between concepts. The relationship between concepts can be articulated in the link captions, for example "leads to" (causal), "consists of" (part-whole), "follows" (temporal), "is inside of" (spatial), "increases" (quantified), or "is different than" (comparison). Nodes (usually nouns) and linking phrases (usually verbs) can be interpreted as a semantic network of propositions.

Difference to Other Forms of Node-Link Diagrams

Various forms of node-link diagrams have been developed for educational purposes. Some of the earliest examples of node-link diagrams were developed by the Greek philosopher Porphyry of Tyros in the third century AD to graphically visualize the concept categories of Aristotle. Commonly used examples of node-link diagrams are mind maps, flowcharts, and concept maps. Mind maps, in which connections are unspecified associations represented by nondirectional lines without linking phrases, are often arranged in a radial hierarchy around a single central concept. Flow charts, first presented by engineer Frank Gilbreth in 1921, show the intermediate steps between input (e.g., problem) and output (e.g., solution) of a system. Flow chart connections are usually ontologically of the same kind, such as information, energy, time, or material. In contrast, linking phrases in concept maps can represent any form of relationship (e.g., temporal, procedural, functional, subset, superset, causal, etc.) and topological arrangement (e.g., hierarchical, hub, decentralized network, circular, etc.).



Concept Mapping, Fig. 1 Concept map about concepts maps (By Beat A. Schwendimann)

Background

One theoretical perspective that influenced concept mapping is that of David Ausubel's assimilation theory [see "► Ausubelian Theory of Learning," "► Meaningful Learning"], which stresses the importance of individuals' existing cognitive structures in being able to learn new concepts. Inspired by this perspective, Joseph D. Novak and his research team at Cornell University developed concept mapping as a means to graphically representing concepts, based on their research on understanding changes in children's science knowledge (1984). With its emphasis on actively engaging learners in eliciting and connecting existing and new concepts, concept mapping is considered as being consistent with a constructivist epistemology, as it aims to support the elicitation of existing and missing concepts and to promote the construction of connections.

Construction of Concept Maps

Concept map setups can vary from open-ended to very constrained forms. Concept mapping tasks with few constraints can provide learners with a focus question while giving them free choice to select their own concepts and links. A "focus question," such as a how or why question, can help students to understand the purpose of the concept map activity and guide their concept map generation. A somewhat more constrained form of activity would provide learners with premade lists of concepts or link captions but give free choice of which concepts to connect. Highly constrained applications of concept mapping would perhaps provide learners with a skeletal network structure and premade lists of concepts or link captions, with which the learner fills in blanks within the structure. Concept maps can be constructed by hand using paper and pencil, flash cards, and post-its or by using computer software, of which there are many educational offerings, including Inspiration and CMap. Research indicates that concept mapping can facilitate the development and revision of concepts with software supports for hyperlinks (e.g., to Web pages or other concepts) and multimedia (Canas 2003). Concept mapping requires initial training to familiarize learners with the concept mapping principles and criteria for concept map evaluation.

Concept Maps and Learning

Concept maps have been applied as learning tools in many science disciplines, including chemistry, biology, earth science, ecology, astronomy, and medicine. They have been used with all ages from children to adults, using individual or collaborative activities, in asynchronous or synchronous formats. Meta-analyses have shown that concept mapping produces generally positive effects on student achievement and large positive effects on student attitudes (Horton et al. 1993; Canas 2003; Nesbit and Adesope 2006).

Concept mapping, especially in its more constrained forms, has also been found to be a reliable and valid form of assessment for changes in students' understanding of science concepts. Research comparing concept maps to multiple-choice tests indicates that concept maps assess different forms of knowledge (e.g., propositional or hierarchical). Concept maps can reveal students' knowledge organization by showing connections, clusters of concepts, hierarchical levels, and cross-links between concepts from different levels. Cross-links are of special interest, as they can indicate creative leaps on the part of the learner (Novak and Gowin 1984).

Concept maps can be analyzed either qualitatively or quantitatively. Quantitative analysis can include concepts, hierarchy levels, cross-connections, propositions, or network structure. The number of links and concepts, while easily countable, provides limited insight into a student's understanding. Propositions are more informative elements of a concept map and can be used to track changes in students' understanding. Proposition analysis can include all links or only a selection and can value all propositions equally or attribute weights differently. Research suggests that scoring only selected propositions can be more sensitive to measuring conceptual change because it focuses only on key concepts of the concept map (Schwendimann 2014). Concept map analysis often compares student-generated maps to an expert-generated map. This approach can provide instant and authoritative feedback but has limits in terms of capturing the wide range of alternative expressions of student understanding. Network analysis methods often focus on elements like network density or the connectedness of selected concepts. Qualitative analysis of concept maps can include changes in types of link captions or topographical analysis methods to describe the overall geometric structure of the concept map.

Applications of Concept Maps

Concept maps can be used in many ways in science education, for example, as tools for lesson planning, as advanced organizers, as learning tools for students, as online navigation interfaces, as knowledge management interfaces, or as assessment tools. Different explanations have been proposed to explain the observed benefits of using concept maps. Concept mapping can support eliciting existing concepts and connections and serve as a memory aid by off-loading them as external node-link diagrams. Concept maps can support learning science by identifying central concepts from different contexts. The explicitness and compactness of concept maps can help learners to maintain a "big picture" view. The "gestalt effect" of concept maps allows for the viewing of many concepts at once, increasing the probability of identifying gaps and making new connections. In a concept map, each concept is represented by only one node, and all connections related to that concept are presented in one location. Concepts derive their meaning in part from their connections to surrounding concepts. Visual chunking of related concepts or the arrangement of concepts in hierarchies can reveal epistemological structures.

Compared to written linear summaries, clustering-related concepts into meaningful patterns can foster quick information retrieval, in part because concept maps use a simple syntax for propositions (node-link-node) and limited amounts of text to represent concepts. Concept mapping can be seen as a first step in ontology building and can also be used flexibly to represent formal arguments. Fast information retrieval from concept maps can be beneficial for collaborative activities. Viewing or generating concept maps may also promote the integration of concepts in both verbal and visuospatial memory. According to Paivio's dual coding theory, the verbal information and the visuospatial information of concepts reside in separate but potentially interlinked memories. Integrating verbal and visuospatial information of concepts can be simultaneously processed and provide alternative ways to retrieve concepts. Finally, the process of translating concepts from texts and images to a node-link format may foster deeper reflections about concepts and their connections and prevent rote memorization.

Limitations of Concept Maps

Similar to geographical maps, concept maps do not aim to include all possible concepts but rather only a selection of meaningful ones. Concept maps usually constrain connections between two concepts to a single relationship, which requires distinguishing and selecting between multiple possible relationships. Concept map construction requires an initial training phase to learn how to generate, interpret, and revise concept maps. Generating, revising, and evaluating concept maps can be time-consuming. More constrained forms of concept mapping can be faster and more reliably evaluated, but they offer limited freedom to express one's understanding. Also, the same concept or linking phrase could take on different meanings for different learners or contexts. Concept mapping activities can be beneficial to improve conceptual understanding but may have limited effects on basic recall.

Implications for Science Education

As a learning tool, concept maps can support eliciting scientific concepts and connections and can make students' organization of concepts visible to themselves and their peers and teachers. Graphic organizers, such as concept maps, can support the integration of students' isolated concepts toward a more organized, interconnected network of concepts. Research indicates that the implementation of concepts maps can shift the epistemological authority from the teacher to the student, reduce emphasis on right and wrong answers, and create visual entry points for learners of varying abilities. Findings suggest that concept mapping may be particularly beneficial for lower performing students by providing scaffolds (e.g., a selection of important concepts) and by modeling active inquiry. When introducing concept mapping, the teacher should make the possible benefits for the learner explicit: that they will help students to reflect, to communicate what would otherwise be incommunicable, and to retain a trace of what otherwise would disappear. Concept maps are cognitive artifacts that help elicit students' concepts and support self-explanations; but they can also be seen as social artifacts through which students communicate or make their ideas accessible to others. When concept maps are generated collaboratively, they become shared social artifacts that elicit existing and missing connections and spur discussion among students and teachers. The constraint to only one link between two concepts requires collaborators to negotiate, creating a genuine need to support arguments with scientific evidence.

Cross-References

- ▶ Alternative Conceptions and P-Prims
- ▶ Assessment: An Overview
- ▶ Concept Maps: An Ausubelian Perspective
- ▶ Conceptual Change in Learning
- ▶ Constructivism

- ▶ Meaningful Learning
- ▶ Mindtools (Productivity and Learning)
- ▶ Prior Knowledge
- ▶ Technology for Science Education: History
- ▶ Technology for Science Education: Research

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Concept Maps: An Ausubelian Perspective

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Keywords

Knowledge Map; Knowledge Visualization

Origin

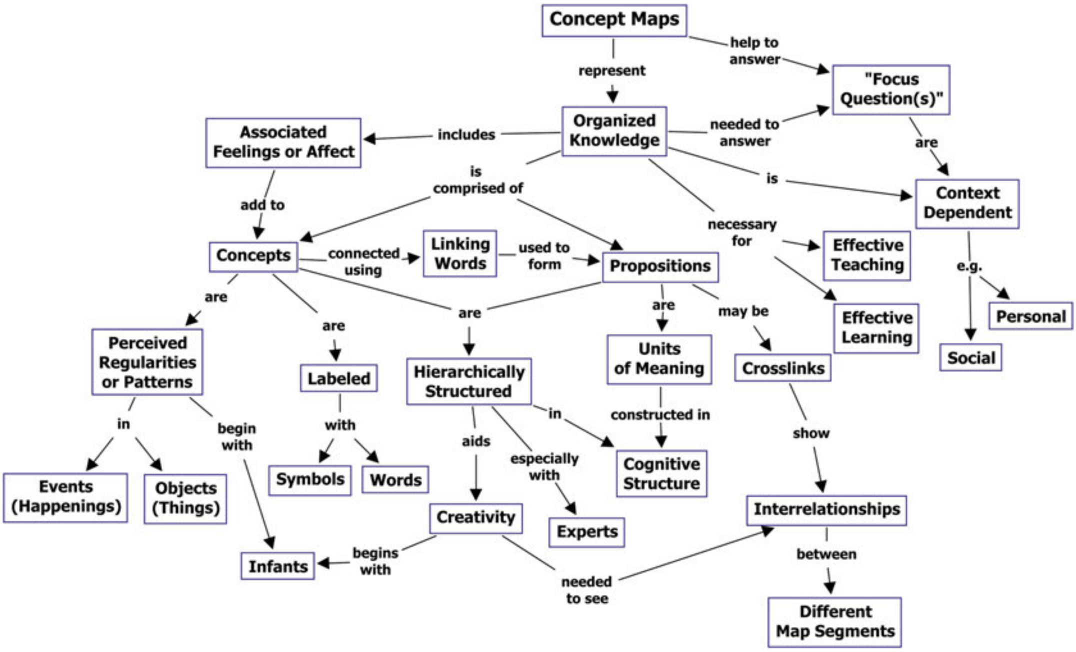
Concept maps were invented at Cornell University in the early 1970s in response to a need to explore growth in conceptual understanding of children in a 12-year longitudinal study of children's learning of science concepts (Novak and Musonda 1991). Audio-tutorial science lessons were provided to children in grades one and two (ages 6–8), and they were subsequently interviewed to assess their understanding of the concepts presented. Similar interviews were done with the same children as they progressed through school through grade 12. Building on Ausubel's assimilation theory of learning and constructivist epistemology, Novak's research group found they could summarize the interviews on a concept map and show specific changes in children's concept and propositional knowledge of basic science concepts over the 12-year span of the study. Figure 1 shows an example of a concept map and describes the nature of concept maps. Figure 2a, b show concept maps drawn from an interview with a child at the end of grade 2 (a) and for the same child at the end of grade 12 (b). The figures show clearly the child's growth in understanding of basic concepts dealing with the nature of matter and energy and also the good organization of this knowledge. These figures illustrate the Ausubelian principles of meaningful learning including subsumption of new concepts and propositions under more general concepts, acquisition of new superordinate concepts, and progressive differentiation of knowledge in this domain.

Application of Concept Maps to Learning How to Learn

Graduate students working on the 12-year study noted above found the use of concept maps helped them learn in the work they were doing. This led Novak to develop systematic approaches to learning how to learn and eventually to a book with this title (Novak and Gowin 1984). The book has subsequently been translated into Arabic, Chinese, Finnish, Italian, Japanese, Portuguese, Spanish, and Thai. Concept mapping and Ausubel's ideas about learning began to be used worldwide.

Development of CmapTools Software

In our early work at Cornell, we made concept maps mostly with pen and paper. While this

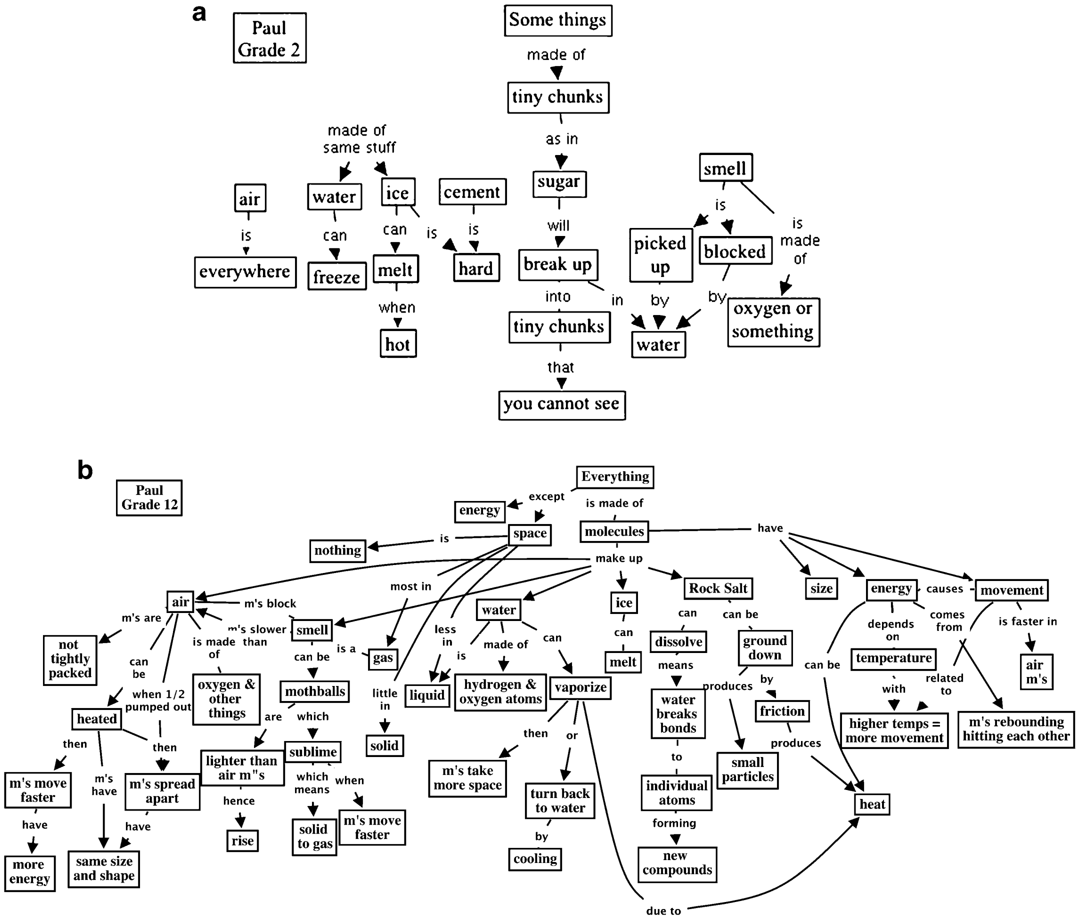


Concept Maps: An Ausubelian Perspective, Fig. 1 An example of a concept map

works well with small concept maps, it becomes very awkward with maps containing 50 or more concepts, especially as one chooses to make alterations to these maps. We used Post-itsTM notes in some of our work, and while these provide for easy team work and easy movement of concepts, changing linking lines and linking words often required completely redoing the whole concept map. As appropriate computer software became available in the early 1980s, we began to use this for preparing maps for publication, but at that time essentially all students lacked computers and/or the software to do concept maps.

In 1987, while on sabbatical leave at the University of West Florida, Novak began working with Kenneth Ford and Alberto Cañas, who later became Director and Associate Director, respectively, of the Florida Institute for Human and Machine Cognition (IHMC). Ford pointed out that the primary problem in the field of artificial intelligence, his specialty, was to find a way to represent knowledge and to extract knowledge from experts in a precise and reliable way. He saw concept maps as a solution to this problem and so began a collaboration that continues today. NASA, the Department of Navy, the National Security Agency, and other US federal and private organizations found the use of concept maps an excellent tool for capturing and archiving expert knowledge and for facilitation of team problem solving. With grants from these organizations, IHMC, under Cañas's leadership, developed excellent software for creating concept maps of the form shown above, CmapTools. This tool makes it easy to show individual concepts in nodes connected by linking lines with appropriate linking words attached and arranged hierarchically. Figures 1 and 2 were drawn using CmapTools, based on the original paper and pencil maps. The software is available at no cost at http://cmap.ihmc.us, a site that also provides access to numerous research studies and other documents that give additional information on concept mapping.

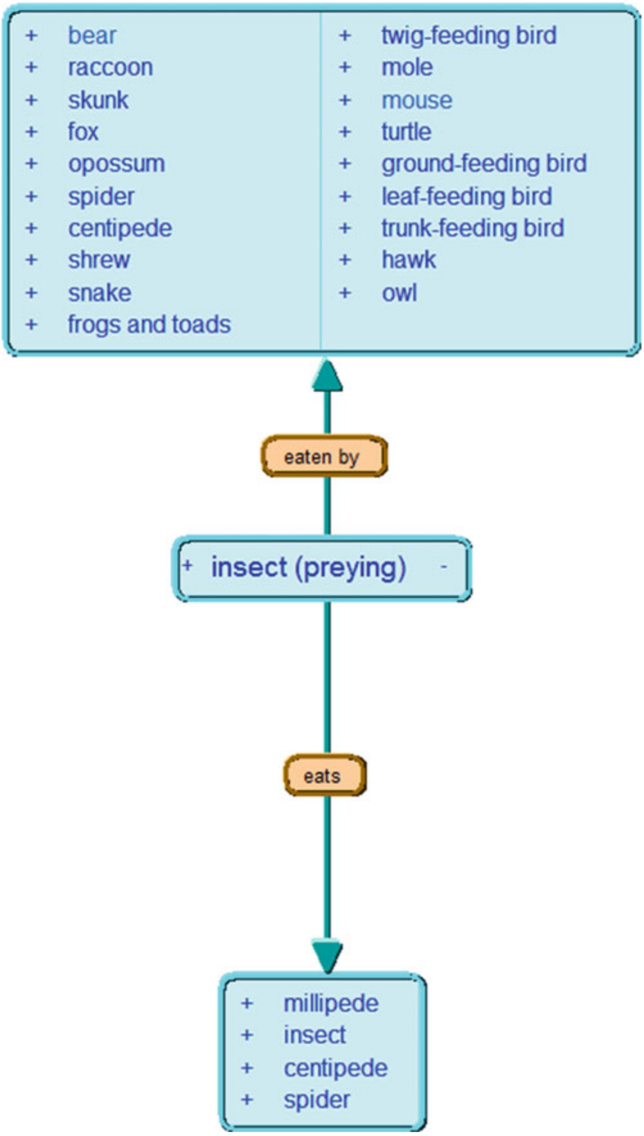
Fisher and her colleagues saw concept maps as a useful tool for identifying and changing student misconceptions/alternative conceptions (Fisher et al. 2000), and Fisher and Faletti created



Concept Maps: An Ausubelian Perspective, Fig. 2 (**a**) Concept map drawn from an interview transcript, grade 2 (age 7) student. (**b**) Concept map drawn from an interview transcript, same student as (**a**), now grade 12 (age 17) (Note how superordinate learning and extensive subsumption and integration of new concepts and propositions have occurred)

SemNetTM software in 1986 (also available at no cost at: http://www.biologylessons.sdsu.edu/license.html). Figure 3 illustrates some of the factual details identified by Fisher and her colleagues that need to be properly assimilated by biology students to overcome some misconceptions and build a valid knowledge structure.

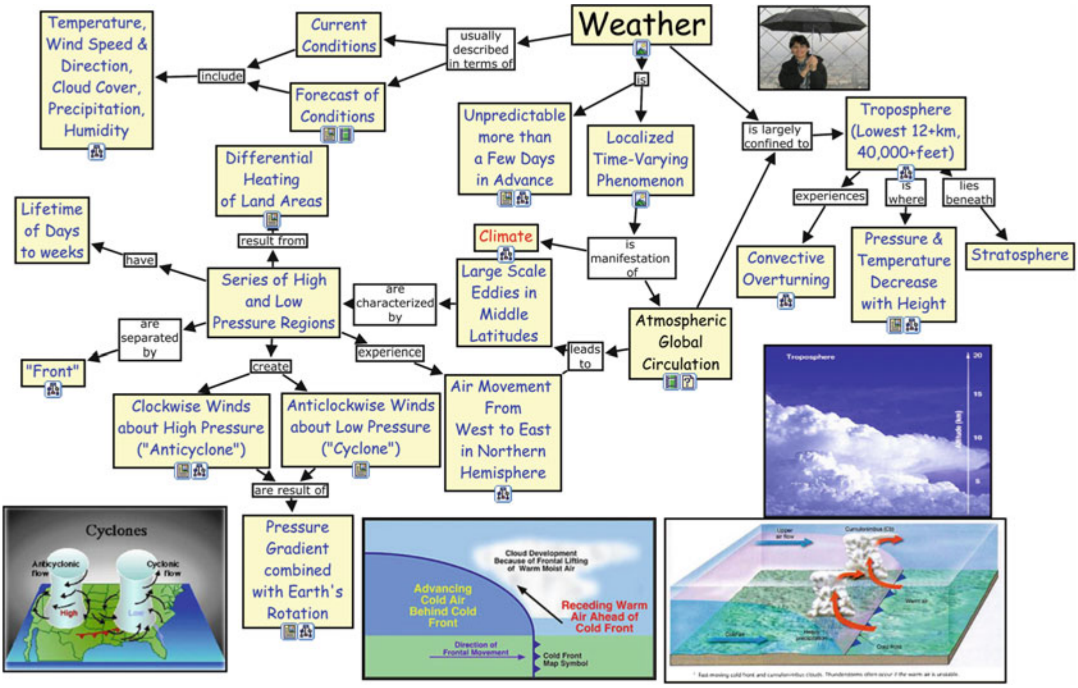
CmapTools has the unique, patented feature that allows a person to attach any digital resource to any concept on a map by simply dragging the icon for this resource to a target concept and dropping it on the concept. This resource becomes part of a "knowledge model" that is stored with the concept map. The resource can be opened by simply clicking on the icon for the resource type and selecting the desired resource. In this way, one can do more than just create a concept map; one can create essentially a digital knowledge portfolio with a broad range of digital resources linked into the map. Figure 4 shows an example of a concept map with resources attached, and inserts show some of the resources that can be accessed via icons at the bottom of concepts. The complete file of concept map and all resources is referred to as a "knowledge model." There are many such "knowledge models"; these can be accessed at http://cmex.ihmc.us.



Concept Maps: An Ausubelian Perspective, Fig. 3 A sample of concepts needed to assimilate properly to understand some biological relationships

Further Developments with Concept Maps: Focus Questions and Parking Lots

As our work with concept maps progressed, we found the clear identification of a focus question the concept map sought to answer was critically important, especially when working with individuals or groups that were seeking to solve some problem. A parking lot is a list of concepts suggested by an individual or group that they deem as important to answering the focus question. This step is usually relatively easy for individuals or groups and in some ways resembles what is done in mind mapping. After identifying pertinent concepts (say 15–20), these are ordered from the most inclusive, most general concept to the least inclusive, most specific concept. Then these concepts are used to begin building the concept map. If computer software is used, this is mechanically quite easy, since concepts from the list can be simply moved into the developing concept map, and then appropriate



Concept Maps: An Ausubelian Perspective, Fig. 4 A sample concept map on weather showing some of the resources that can be accessed via icons attached to concepts (From Briggs, with permission)

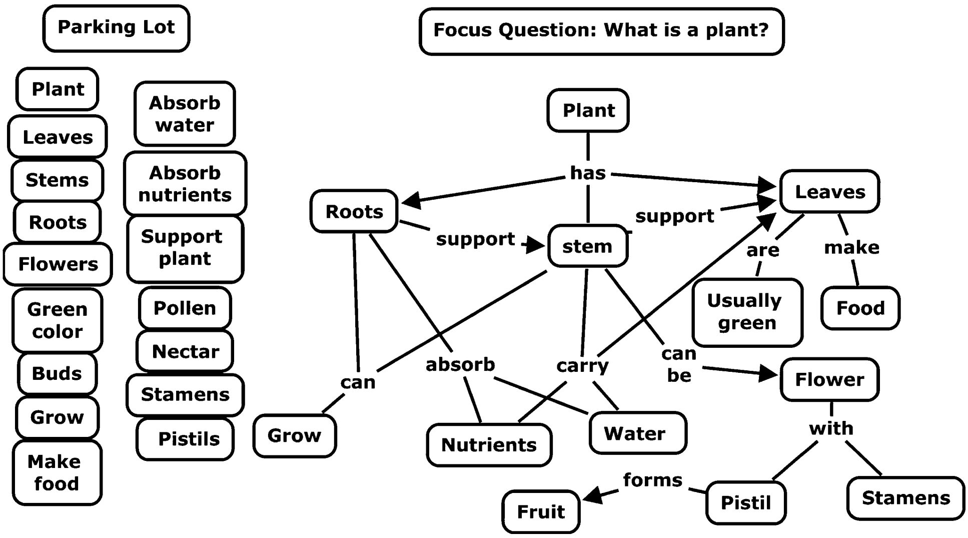
linking words can be added. Figure 5 shows an example of a concept map so created. This map can be elaborated by adding pictures, video clips, etc. Because of the importance seen in the development of a good focus question for good concept mapping, the CmapTools software has this built into its protocol.

Often, with older groups in particular, as they began to build a concept map, they see the original focus question is not actually the central question they are trying to answer. It is then common for a group to modify or even completely change their focus question as they began to map concepts and propositions pertinent to the question.

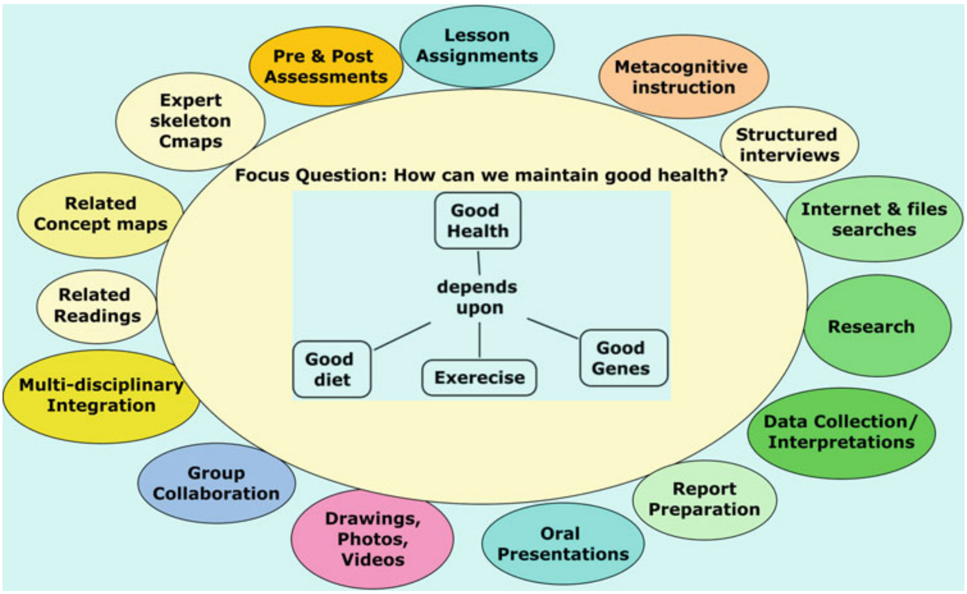
Focus questions may deal primarily with the structure of an object or an event of interest or they may deal with the process of creating an object or event. Sometimes when mapping a sequence of events dealing with some process, maps can be more cyclic or flow chart in form. Depending on the kind of question to be answered or the purpose of the concept map, the structure of a good concept map can vary (Derbentseva et al. 2006). However, we have found hierarchical structures to often be the most useful.

Concept Maps as Metacognitive and Metaknowledge Tools

Constructing a concept map requires a learner to identify key concepts in the material and to show meaningful relationships between concepts as explicit propositions. Moreover, to arrange these concepts into an appropriate structure takes further thought and action. To do this well, the learner must engage in relatively high levels of meaningful learning, and concept maps have been shown to be powerful aids for achieving high levels of meaningful learning in virtually every discipline and from preschool to adult research teams. The more learners engage in concept mapping, the more keenly they become aware of the central role that concepts play in meaningful learning and in understanding any



Concept Maps: An Ausubelian Perspective, Fig. 5 A concept map about plants, showing the focus question used to begin and a parking lot



Concept Maps: An Ausubelian Perspective, Fig. 6 Schematic showing how to employ a new model for education using CmapTools, via an expert skeleton concept map on health, WWW, and other resources (identified in smaller ovals) integrated together into one digital file

domain of knowledge. In short, they become better learners.

We often hear science defined as an organized body of knowledge, but seldom are we shown exactly what this means. As learners become skilled in concept mapping, they become acutely aware of the organized concept and propositional nature of science. If they also engage in science project work, they see sharply how concept and propositional knowledge guides the creation of new knowledge in any discipline. In short, they become aware of the nature of and construction of new knowledge. This consequence is part of the reason for concept maps being valuable as “metacognitive and metaknowledge tools.” More generally, since tools that facilitate learning can also be seen and used as metacognitive tools, concept maps are important tools for developing metacognition. This is demonstrated by both the *Learning How to Learn* book (Novak and Gowin 1984) and by the value of concept maps as one significant strategy in the classroom-based approaches to enhancing student metacognition in the Project for Enhancing Effective Learning.

CmapTools Make Possible a New Model for Learning

As noted above, from 1987 and continuing today, IHMC worked to refine and add functionality to what evolved into CmapTools. Also during this period, there were exponential increases in computer power in personal computers and materials available on the World Wide Web. Among the features developed in CmapTools were means for easy collaboration between learners and mapmakers permitting easy collaborative learning and virtually unlimited information on any topic. In 2004, Novak and Novak and Cañas proposed a new model for education that employs the power of collaborative learning utilizing CmapTools, a wide range of learning activities, the relatively unlimited WWW resources, and expert skeleton concept maps to scaffold early learning.

The idea behind expert skeleton concept maps is to provide some initial conceptual guidance to a team of 2–4 learners who subsequently engage in a variety of learning activities, as depicted in Fig. 6. Prepared by experts, the expert skeleton concept maps serve to define an important domain of knowledge to be studied and also provide cognitive scaffolding to make it easy for an accurate starting point for organizing knowledge in this domain. Learners who have used expert skeleton concept maps in this way have reported considerable merit in this use, particularly in impact on learning of concepts. They value expert skeleton concept maps; their value in reducing the problem of prior misconceptions still needs to be researched. The teacher’s role is primarily to serve as a guide and coach and also to model her/his own learning as the student’s progress on their projects. As students do WWW searches, their own interviewing of experts, experimentation, reading, etc., they record their progress using CmapTools to create a comprehensive knowledge model. Figure 6 illustrates how, using CmapTools and building on an expert skeleton concept map, materials from all other forms of learning can be combined into a digital knowledge portfolio. These can be stored for future reference or used to further elaborate understanding in this domain of knowledge. Such portfolios have powerful potential, including if used from an early age and then throughout schooling.

Cross-References

- ▶ Ausubelian Theory of Learning
- ▶ Concept Mapping
- ▶ Conceptual Change in Learning
- ▶ Constructivism
- ▶ Cooperative Learning
- ▶ Meaningful Learning
- ▶ Metacognition and Science Learning
- ▶ Multimodal Representations and Science Learning
- ▶ Project for Enhancing Effective Learning (PEEL)

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Conceptual Change in Learning

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Keywords

Cognition; Conceptual Change; Conceptual Understanding

Introduction

With his idea that the most important factor influencing learning is what a learner already knows, Ausubel could in some ways be argued to have started a new and still ongoing research area at the end of the 1960s: conceptual change. Since then, a very large volume of research has addressed students' understanding of a given topic and how it changes with different ages or as a result of instruction. The notions of "concept" or "conception" are used to describe a certain piece of knowledge which has to be learned by a student (concept) or refer to the understanding a student holds at a particular point in time (conception, alternative conception, or misconception). "Conceptual change" describes and assesses how naïve, nonscientific, or "wrong" conceptions develop to become improved, scientific or "correct" concepts. Predominantly, research on conceptual change is based on a constructivist epistemology assuming that concepts are a result of personal or social constructions.

During the last 40 years, strong evidence has been gathered that students entering a science classroom typically hold conceptions which are very different to those of scientists. In order to adapt instruction to students' prior ideas, research has aimed to assess students' conceptions in various science topics. The body of literature describing content-specific conceptions involves studies that number, literally, in the thousands and is still noticeably increasing. Issues addressed are not only subject-matter concepts but also students' ideas about nature of science (NOS) or scientific inquiry (SI) and their concepts about learning.

Even though conceptual change has a relatively long research tradition and some basic assumptions are shared, there are also noticeably differences between frameworks used to describe conceptual change (e.g., Duit and Treagust 2003; Scott et al. 2007). Coming to terms with conceptual change research is not only difficult because theoretical frameworks differ, but also because the focus on concepts and conceptual change can be very different. Concepts and conceptual change can be addressed from a social or an individual perspective. Whereas the first perspective aims to describe how communities (e.g., scientists, engineers, or classmates) create, develop, and share concepts which are new for the community (Thagard, pp. 374–387 in Vosniadou 2008), the latter describes how concepts are developed by individuals (e.g., scientists or students). Furthermore, conceptual change research can address expert learning (scientists, engineers) or novice learning (students). In science education research, the vast majority of work in conceptual change aims to describe and explain students' difficulties in establishing fundamental scientific concepts by adapting an individual perspective. In addition, the transition from a naïve to a more scientific understanding is investigated, and how this process can be best promoted. In this line of research, it is stressed that conceptual change should not be confused with the notion of learning: Conceptual change is part of learning but not all learning is conceptual change (e.g., Vosniadou, p. 1 in Vosniadou 2013).

This entry is dedicated to Phil Scott.

Even though science education researchers can share the observation that students hold particular misconceptions in various topics, the assumed reasons why these misconceptions exist and why learners are resistant to change cannot be observed directly. As a consequence, theoretical frameworks have taken different routes depending on the assumptions as to what are the main barriers for conceptual change. Among the different approaches which can be identified, four frameworks are frequently mentioned: the "classical conceptual change approach" which was introduced during the 1980s and developed further by Strike and Posner (1992), Vosniadou's "framework theory approach" (Vosniadou et al., pp. 3–34 in Vosniadou 2008), Chi's "categorization approach" (Chi, pp. 61–82 in Vosniadou 2008), and diSessa's "knowledge in pieces approach" (diSessa, pp. 29–60 in Limón and Mason 2002). Even though these four frameworks frequently appear in association with conceptual change, other frameworks can be identified which also seem to describe issues of conceptual change, for instance, Marton's "phenomenographic approach" (Marton and Pang, pp. 533–559 in Vosniadou 2008), Stavy's "intuitive rules approach" (Stavy et al., pp. 217–231 in Limón and Mason 2002), or von Aufschnaiter's "level approach" (von Aufschnaiter and Rogge 2010). Even though the frameworks differ, they all have a primary focus on the same three broad questions:

- What are concepts? Is there any other knowledge or understanding which is "more" than a concept or "less"?
- What are the mechanisms by which conceptual change takes place? Why is particular conceptual understanding difficult for students to achieve?
- How can conceptual change be promoted?

Within the following sections, issues addressed with these three questions are discussed with reference to the frameworks offered by Chi, diSessa, Strike and Posner, and Vosniadou, as well as, where it applies, Marton, Stavy, and von Aufschnaiter.

Concepts

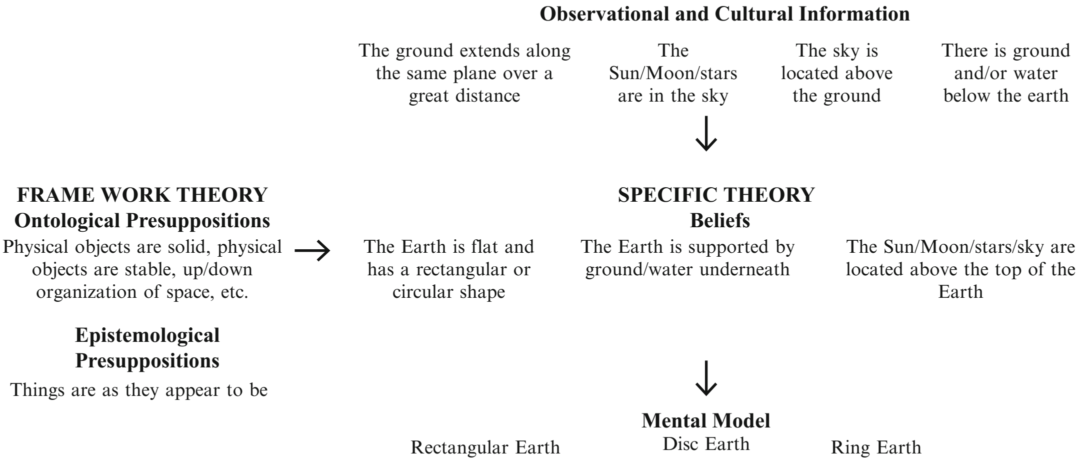
Within the different frameworks, different notions for concepts are used (for instance, belief or coordination class), and also understanding of the same terms (such as mental model) can vary. Thus, frameworks cannot be compared easily. However, common to most frameworks is the (usually implicit) idea that concepts are specific mental elements and refer to an understanding of certain principles (e.g., von Aufschnaiter and Rogge 2010). Moreover, most frameworks assume that human cognitive structure is composed of more than one type of mental element. The notion of grain size is often used to express that "smaller" and "larger" mental elements are considered (see Table 1). Grain size can differ in two ways: Typically, mental elements of smaller grain size form an interrelated set to establish mental elements at greater grain size which have the character of networks. Grain size can also refer to the context specificity of mental elements. Here, elements at smaller grain size refer to a particular context whereas mental elements at larger grain size are assumed to encompass varying contexts. Common to the majority of the frameworks is the idea that the cognitive structure described is central in organizing individual thought and learning (Strike and Posner 1992, p. 148).

In Strike and Posner's framework, the cognitive structure is composed by a conceptual ecology which comprises learners' knowledge and of which concepts are constituent parts. Different sorts of concepts are integrated into the conceptual ecology, such as organizing concepts, analogues concepts, metaphors, or epistemological beliefs. Vosniadou describes a more elaborated idea of the cognitive structure (Fig. 1) in which unspecific framework theories have an impact on specific theories in which beliefs have the status of concepts. From these theories, mental models are formed while individuals make sense of the current situation (such as a task, a problem, or a question).

In diSessa's approach, the cognitive structure is composed of coordination classes which have

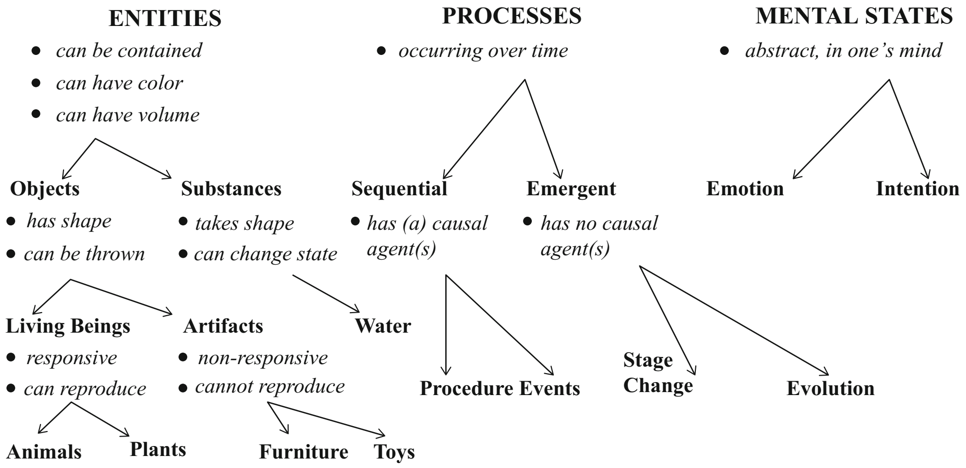
Conceptual Change in Learning, Table 1 Grain size of mental elements described in different frameworks

Approach	Grain Size Small	⟶	Grain Size Broad	Grain size increases with
Chi	belief	—	mental model	interrelationship between elements; classification can also differ (ontological categories or "lower" categories, see Figure 2)
diSessa	p-prim	— readout strategy, causal net —	coordination class	interrelationship between elements (only coordination classes have the status of concepts)
Strike & Posner	concept	—	conceptual ecology	interrelationship between elements
Vosniadou	mental model	— belief (part of specific theory) —	presupposition (part of framework theory)	reducing context specificity (only beliefs and presuppositions have the status of concepts)



Conceptual Change in Learning, Fig. 1 Conceptual structure described by Vosniadou (similar to Vosniadou et al., p. 8 in Vosniadou 2008)

the status of concepts. These coordination classes are an integration over causal nets as a knowledge base and readout strategies as ways in which current situations are observed. As very basic mental elements, unrelated phenomenological primitives (p-prims) are described which are applied to everyday situations. An example of a p-prim is "force as a mover." In similar ways, Stavy assumes that activities of learners are often established from underlying intuitive rules.



Conceptual Change in Learning, Fig. 2 Ontological trees with hierarchical and lateral categories described by Chi (similar to Chi, p. 58 in Vosniadou 2013; see also Chi, p. 64 in Vosniadou 2008)

In contrast to diSessa, Stavy argues that only a limited number of intuitive rules can be identified, whereas diSessa assumes that a very large number (several hundreds) of p-prims exist.

In Chi's framework, a mental model is an organized collection of beliefs and has either the status of a concept or a system of concepts. In addition to distinguishing between mental models and beliefs, Chi argues that mental elements refer to ontological categories which classify as to whether the mental model and its beliefs are about entities, processes, mental states, or another category not yet identified (Fig. 2). Different ontological categories do not belong to the same tree (capitalized terms in Fig. 2) whereas lateral properties do. Categories of different trees or different branches do not share properties, for instance, a tennis match can last 200 min (processes) but cannot be green (entities). Thus, the network character in Chi's approach has a more hierarchical layout than typically described in other frameworks. As a consequence, ascribing a grain size to ontological categories (see Table 1) does not make much sense as these are used to classify mental models and beliefs which themselves have different grain sizes.

Research Debates About These Frameworks

(a) *Coherency of cognitive structures*

Among different ideas as to what limits students' understanding of science concepts, two distinct reasons are frequently discussed. For many researchers, an individual cognitive structure is composed of a coherent set of mental elements which have been established via repeated everyday experiences and are therefore stable and resistant to change (e.g., Chi, Strike and Posner, Vosniadou). On the other hand, some researchers argue that students' conceptual understanding is limited because the underlying conceptual structure is not very coherent. Even though there is an ongoing debate about the issue of coherency (e.g., diSessa, pp. 31–48 in Vosniadou 2013), there is not as yet any resolution between these two clearly contrasting positions. It has to be stressed that empirical evidence aiming to clarify the issue as to whether a learner's knowledge base is coherent is difficult to gather as the underpinning assumptions about conceptual structures heavily influence how evidence is gathered and interpreted.

(b) *Mental elements versus situated constructions*

The large majority of conceptual change frameworks describe specific mental elements which are assumed to determine individual activity (e.g., Chi, diSessa, Posner and Strike, Vosniadou; see Table 1). In contrast, some researchers argue that concepts are constructed from moment to moment and refer to ways in which a particular situation is experienced (e.g., Marton, von Aufschnaiter). Thus, these latter researchers do not claim any specific layout of a cognitive structure; rather, they investigate variability and stability of a learner's ongoing activity. They also stress that research needs to take care that a learner's utterance is not interpreted from the researchers' point of view (first-order perspective) but needs to be investigated from the learner's point of view (second-order perspective).

(c) *Usefulness of prior conceptions*

Conceptual change research typically focuses on those conceptions which are "wrong" (misconceptions) and have to be developed to more scientific ("correct") concepts. Thus, research is oriented towards learners' mistakes rather than towards the potential of their initial ideas (Halldén et al., pp. 509–532 in Vosniadou 2008). With their focus on areas in which students typically hold misconceptions, the frameworks are also limited in their power to explain why sometimes correct conceptions are established and what exactly differentiates situations with successful concept formation from those in which misconceptions are established. In order to have a more productive approach towards students' conceptions, those aspects of existing conceptions which can be used successfully to develop a student's conception further should be understood and taken into account.

Conceptual Change

The notion of conceptual change covers the description and analysis of how a learner or a group of learners (including expert learners) progress from prior conceptions to disciplinary or new scientific knowledge. In science education research, typically students' conceptual change is investigated by interpreting their written answers or statements, utterances, and/or drawings. Overall, two fundamentally different approaches can be identified. Those researchers who model a cognitive structure infer specific mental elements from students' products. Afterwards, these elements are classified, partly by using content-specific categories (e.g., diSessa, Vosniadou; see Fig. 1) or by more general categories (e.g., Chi; see Fig. 2). Researchers, who do not aim to describe cognitive structures which determine individual activity, classify students' products and utterances directly. Again, classification can either be content specific (e.g., Marton) or using more general categories (e.g., von Aufschnaiter).

In order to distinguish conceptual change that is more likely to occur or is less demanding for a learner from change which requires larger revisions, some authors introduce the distinction between "weak" and "strong" restructuring. Similar to the idea of grain size, "weak" revisions (also labeled as "assimilation" or "conceptual capture") are considered to be smaller and/or less demanding, whereas "strong" revisions ("accommodation" or "conceptual exchange"; see Duit and Treagust 2003) are considered to heavily affect the knowledge base and should therefore be harder to achieve. The distinction between weak and strong can be used to provide an overview about conceptual change dynamics described in different frameworks (see Table 2). Table 2 also contains some information about the conditions seen to be needed for conceptual change which are described in the different frameworks. It should be stressed that the overview in Table 2 is meant to give a brief introduction and serve as an orientation. As such, it cannot communicate all details of the different frameworks.

Concepts and conceptual change are typically assessed by interviews or tests. A widely known example of the latter is the "Force Concept Inventory" which was initially developed by Hestenes, Wells, and Swackhamer; its revised version was developed by Halloun, Hake, Mosca, and Hestenes and is available online (http://modeling.asu.edu/R&E/Research.html [accessed

Conceptual Change in Learning, Table 2 Brief overview of conceptual change described in different frameworks

	Weak restructuring	Strong restructuring	Remarks
Chi	*Revision and transformation*: False beliefs and flawed mental models ("inaccurate misconceptions") are revised and transformed	*Schema creation and categorical shift*: Not yet established (ontological) categories are created and/or "incommensurate misconceptions" assigned to another category	If information is only added to belief/mental model, this is not considered as conceptual change Missing categories and tree swapping between ontological categories are demanding
	Conditions of conceptual change: Weak restructuring can be based on refutation; strong restructuring requires information on alternatively available categories and may require to build (a) new category/categories		
diSessa	*Development of a "sense of mechanism"*: Priority of p-prims being activated in specific situation changes (cuing priority), development of new p-prims, or established p-prims are expanded to more situations	*Development of coordination classes*: Causal nets or readout strategies are expanded, integration of causal net and readout strategy is improved, or coordination class can be aligned to a larger number of situations	Learning difficulties can be caused by single p-prims, not-well-established causal nets, or readout strategies Conditions for conceptual change not described in detail
	Conditions for development of coordination classes: Causal nets emerge when coherency across p-prims is established		
Marton	*Development from undifferentiated to differentiated way of experiencing*: More aspects of a phenomenon considered or more interrelation of aspects, reaching higher levels of ways of experiencing		Does not differentiate between weak and strong
	Conditions for development of ways of experiencing: Create focus on specific aspect of phenomenon (relevance structure) and vary aspect systematically		
Strike and Posner	*Assimilation*: Integration of a new concept into existing cognitive structure (alternatively: conceptual capture, Hewson 1981)	*Accommodation*: Major revision of existing cognitive structure in order to establish new conceptual understanding (alternatively conceptual exchange, Hewson 1981) *Conditions for accommodation*: Dissatisfaction with prior conception, new concept has to be intelligible, plausible, and fruitful	Description based on Piagetian theory and on philosophy of science Accommodation should not be confused with abrupt change, can be gradual and slow, but results in major revisions
von Aufschnaiter	*Development of concepts*: From exploration (level I) to formation of intuitive rules (level II) to the development of phenomenon-based concepts (level IIIa) which are established by generalizations over concrete experiences. Model-based concepts (level IIIb) are developed late in learning processes. Iteration in levels constitute learning dynamics		Does not differentiate between weak and strong Model-based concepts are considered being more difficult for learners Understanding can be "correct" or "incorrect" at all levels
	Conditions for conceptual development: Establish experiences that match the concept to be developed, create opportunities to rediscover already "established" concepts, do not introduce model-based concept at early stages of learning of particular content		
Vosniadou	*Enrichment*: New information is added to existing cognitive structure without alteration of structure	*Revision/replacement*: If new information is in conflict with existing conceptual structures, either elements or their interrelationship have to be revised/changed *Conditions for conceptual change*: Rather than a mental model itself, beliefs and presuppositions have to be changed; metacognitive reflections are important for this change	Revision of framework theory more demanding than revision of specific theory Revision slow and gradual because of stability of beliefs and presuppositions

October 7, 2013], background articles can also be downloaded from that website). A prominent example of conceptual change interviews is Vosniadou's work about children's mental models of the earth (e.g., Vosniadou et al., pp. 3–34 in Vosniadou 2008). Both approaches, tests and interviews, seek to identify individual conceptions and, often via a pretest-posttest design, how these change as a result of instruction. Furthermore, conceptions of individuals at different ages or grades are often compared. Whereas interviews are often chosen to explore details of students' conceptions with a limited number of participants, tests are widely used to investigate students' conceptions with a large number of participants. Here, multiple-choice formats which offer common student misconceptions along with scientific answers can be analyzed objectively and quickly.

Research Debates About Conceptual Change

(a) *Replacement versus revision*

Even though the notion of "conceptual change" implies that prior concepts are replaced by scientific conceptions, it is widely accepted that conceptual change needs to be regarded as a more gradual and slow process (see also last column in Table 2 and Duit and Treagust 2003). Further, even if a scientific concept is already established, learners (and experts) may very well still use a prior/alternative conception depending on the problem or the context with which they are dealing. It is assumed that during learning, the status a specific prior conception has for a learner decreases over time while the status of a more scientific concept increases (e.g., Hewson 1981; see also the idea of cuing priority of p-prims in diSessa's framework).

(b) *Lacking focus on processes of conceptual development*

As noted above, conceptual change is typically either assessed by comparing results of interviews or tests between individuals of different age/experience or assessed pre- and post-intervention. These procedures can detect change as a result of instruction, experience, or age but they cannot inform research and practice about either the processes by which change has taken place or how new concepts have evolved. So far, only a limited number of projects have paid attention to the development of concepts while students learn (diSessa, p. 58 in Vosniadou 2008; von Aufschnaiter and Rogge 2010). It is noticeable that ideas on how to promote conceptual change (see below) and interventions based on these ideas are only rarely assessed by addressing the processes by which conceptual change occurs. Thus, for effects detected it is not fully clear which specific component of the intervention will have caused the effect. Also, information about what exactly "gradual" and "slow" might empirically mean is still lacking.

(c) *"Cold" conceptual change*

Conceptual change has frequently been criticized for its dominant focus on cognition. Pintrich and others (1993) have argued that this kind of research is about "cold conceptual change," paying little attention to emotional and motivational factors or the social environment which can affect conceptual change (see also Strike and Posner 1992). These noncognitive factors will help to understand why learners who seem to have a very similar knowledge base progress differently in their conceptual understanding. Assessments for conceptual change have also been criticized because they do usually not include interaction with peers which can have an effect on which understanding is demonstrated by a learner. Furthermore, as to whether concepts identified within a specific context can be transferred to other contexts (within the same topic) or are activated under varying social conditions is rarely investigated (see also diSessa, pp. 43–51 in Limón and Mason 2002).

Promoting Conceptual Change

In order to develop approaches for promoting conceptual change, it is helpful to analyze first why some conceptual change seems to be more demanding or difficult for learners (see also Table 2, last column). Some researchers argue that the stability of conceptual structures which already have a high integration makes the development of different structures difficult (Strike and Posner, Vosniadou). However, these researchers might not be able to explain well why knowledge which is completely new to a learner and not in conflict with existing ideas (especially likely for younger children) can still be difficult to learn. Other researchers, in contrast, assume that learning is challenged by the integration of unrelated elements (e.g., diSessa). These researchers might struggle with explaining why contradictory knowledge (at the same grain size) can also be difficult. For Chi, categories of the different ontological trees (see Fig. 2) over which a learner does not have command or assignment of ideas to a wrong category are major learning obstacles.

Across the different frameworks, several researchers stress that misleading, missing, or incomplete everyday experiences can cause learning difficulties. These existing and missing prior experiences may, for instance, cause a learner to create synthetic models being a mix of correct and incorrect ideas or the learner might add information rather than revise ideas (Chi, Vosniadou). In addition, prior experiences are assumed to often hamper a learner in focusing on relevant aspects of a situation (diSessa, Marton, von Aufschnaiter). Von Aufschnaiter and Rogge (2010) also stress that the nature of specific scientific concepts makes them difficult per se: Concepts that cannot be extracted from observable features (e.g., the concept of energy) are called model-based concepts. It is argued that learners fairly often do either not grasp these scientific concepts or misunderstand them. Researchers who adopt a Piagetian theoretical position may argue that children cannot establish particular concepts because of lacking general cognitive abilities to reach a formal operational stage. However, empirical evidence indicates that conceptual understanding can be reached at fairly young ages.

Even though different ideas exist as to what makes conceptual change difficult for learners, it is widely assumed that in order to promote conceptual change, learners need to be exposed to cognitive conflict (see also Table. 2 “Conditions for. . .”). Based on prior work, Strike and Posner (1992; see also Duit and Treagust 2003; Hewson 1981) have introduced four conditions necessary for conceptual change: (1) First a learner needs to be dissatisfied with his/her existing conception. Dissatisfaction is likely to occur if conflicting information is offered or problems cannot be solved successfully with existing conceptions. (2) Then the new concept which is introduced must be intelligible to the learner, (3) the new concept must be plausible, and (4) the new concept needs to be fruitful in helping a learner to solve problems. The more these four criteria are fulfilled during learning, the more likely it is that conceptual change will occur and scientific concepts receive a higher status for a learner (Hewson 1981; see also Duit et al., pp. 631–632 in Vosniadou 2008). However, it should be noted that how to identify which information is likely to be intelligible or plausible at a specific stage in learning is not yet well described. In addition to establishing cognitive conflict, it is often stressed that metacognition is an important process for a learner to become aware of the conflict (Chi, Stavy, Strike and Posner, Vosniadou). During metacognition, the differences between individual and disciplinary concepts should be made explicit and reasons should be identified why a learner holds a particular conception. In some contrast to other approaches, both Marton’s and von Aufschnaiter’s frameworks do not have a primary focus on cognitive conflict but rather stress the importance of specific experiences. For conceptual change, they argue, specific variations in phenomena are considered to help a learner to discover or “discern” (Marton) underpinning patterns and rules.

It is obvious for the frameworks described that conceptual change is considered as an individual process. However, as already mentioned at the beginning of this entry, conceptual change can also be observed and assessed among a community of (expert) learners. An argument for the common individual focus on conceptual change is the reference to constructivism:

Individual meaning making can be shaped but not determined by any social situation or artifact. On the other hand, individual contributions to a social environment change the environment and the artifacts everyone can use for his/her own constructions. Therefore, conceptual change has always a social component (see debates about "cold conceptual change" above). This interplay between a social and an individual plane for conceptual change and the necessity to create an optimal difference between what an individual knows and the knowledge of a community to which the individual can adapt is sometimes described with Vygotsky's zone of proximal development.

Research Trends in Conceptual Change

Over the last 30–40 years, conceptual change research has covered several science topics in great detail. These include mechanics and electricity in physics, the particle model in chemistry, and students' understanding of evolution in biology. However, various topics are not yet fully examined which are currently explored, for instance, students' understanding of radioactivity. Identifying fundamental concepts and how these have been developed by scientists and students does not exclusively belong to science education. Thus, conceptual change research has been expanded to other areas such as mathematics or social sciences. By expanding conceptual change research to domains other than science, the validity of frameworks which use categories not bound to specific content (e.g., Chi's categorization approach or von Aufschnaiter's level approach) can be analyzed.

In addition to expanding conceptual change to other topics and subjects, the focus has become more developmental: Rather than just identifying incorrect conceptions and aiming to change them to correct conceptions, the necessary and important intermediate steps are considered. Research on learning progressions takes into account that conceptual development is more a gradual process than a sudden shift from naïve to scientific ideas. Approaches towards learning progressions cover both the analysis of fundamental concepts and how their progression should be organized in a curriculum as well as how students' progress in their understanding of fundamental science concepts (Alonzo and Gotwals 2012). The latter approach considers current debates on conceptual change and stresses the relevance and usefulness of prior conceptions.

In addition to cognitive aspects of conceptual change, research has been addressing the challenge of expanding frameworks and empirical approaches towards including motivational, emotional, and social aspects. Even though it is obvious that a more inclusive approach towards conceptual change is needed, it is also evident that both theoretical frameworks and empirical approaches become more complex. Designing investigations which control variables such as motivation, emotion, cognition, and social setting is very demanding.

Besides more content-related aspects of future development, technological and methodological advancements offer new opportunities for conceptual change research. Video recording in classroom and laboratory settings has become more prominent and helps to understand better how concepts are established, used, and changed while students are exposed to learning material over a longer period (von Aufschnaiter and Rogge 2010). Whereas video is an approach typical for smaller sample sizes, item response theory (such as Rasch analysis) which has been established in science education research during the last years can be used to gather information on students' knowledge with larger sample sizes. Here, ordered multiple-choice items are helpful in understanding better how learners progress to a scientific understanding. Taking recent developments into account, it can be expected that a revised and extended conceptual change research will remain a major research focus also during the twenty-first century.

Cross-References

- ▶ Alternative Conceptions and Intuitive Rules
- ▶ Alternative Conceptions and P-Prims

- ▶ Alternative Conceptions/Frameworks/ Misconceptions
- ▶ Constructivism
- ▶ Didactical Contract and the Teaching and Learning of Science
- ▶ Emotion and the Teaching and Learning of Science
- ▶ Inquiry, As a Curriculum Strand
- ▶ Learning Progressions
- ▶ Metacognition and Science Learning
- ▶ NOS, Measurement of
- ▶ Pedagogical Content Knowledge in Teacher Education
- ▶ Piagetian Theory
- ▶ Prior Knowledge
- ▶ Socio-Cultural Perspectives on Learning Science

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Conceptual Profile

▶ Heterogeneity of Thinking and Speaking

Concrete and Formal Reasoning

▶ Piagetian Theory

Constructivism

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Keywords

Cognitive constructivism; Critical constructivism; Personal constructivism; Radical constructivism; Social constructivism

Introduction

For nearly 50 years, constructivist theory has been making a significant contribution to education, shaping the way we think about the active role of the mind of the learner, whether student, teacher, or researcher. But to answer the question “what is constructivism?” is not an easy task; it depends on which version of constructivist theory we are asking about. There are many versions of constructivism in the literature, with labels such as cognitive, personal, social, radical, cultural, trivial, pedagogical, academic, contextual, C1 and C2, and ecological. And there are also allied terms that have a strong family resemblance, including social constructionism, enactivism and pragmatism. For this entry, I consider four versions – personal constructivism, radical constructivism, social constructivism, and critical constructivism. These have had a major impact on science education and greater impacts than other forms/versions. I start with a brief consideration of Piaget's cognitive constructivism, which laid the foundations for the emergence of the "Big Four," and I conclude with an integral perspective on using different versions of constructivism to shape science teaching and learning.

Cognitive Constructivism

By the second half of the twentieth century, science educators had begun to move away from behaviorist theories of learning, especially classical stimulus–response conditioning which was criticized for shaping teaching approaches that privilege learning by memorization and rote recall. The successor to behaviorism was the cognitive constructivism of Jean Piaget, in particular his theory of mental operations and age-related developmental stages of reasoning (from the concrete operational reasoning of early childhood to formal reasoning of the mature adult mind). Piaget's ideas persuaded science educators to take account of the active "constructing" mind of the individual student which had been largely overlooked by the dominant teaching method of lecturing to silent classrooms. Teachers began to reevaluate their established practice of "transmitting" knowledge to the seemingly empty minds of students, realizing that students' failure to learn meaningfully could not necessarily be overcome simply by lecturing more slowly or more forcefully. A radical shift in pedagogical perspective from didactic teaching inputs to students' meaningful learning experiences formed the basis of the constructivist revolution in science education.

Personal Constructivism

Based on research in the 1970s/1980s on "children's ideas" by leading science educators such as Rosalind Driver, personal constructivism captured the imagination of science educators worldwide and led to an ongoing and fruitful program of research into students' conceptions of the physical world. Researchers discovered that students' intuitive understandings of their experiences are so strongly held that in many cases they block development of counterintuitive scientific concepts. For example, the child's experience of applying a constant force to the pedals of a bicycle to maintain constant speed is very often seen by the child as completely contrary to Newtonian dynamics which holds that constant force applied to a point mass on a frictionless surface yields accelerated motion. In the past 30 years, almost every topic in the science curriculum has been researched to identify sources of potential student misconceptions. As a remedy, researchers developed "conceptual change" teaching strategies that enable students to experience dissatisfaction with their naïve understandings and to experience the "intelligibility, plausibility, and fruitfulness" of scientific replacement concepts, aided by metacognitive strategies for reflecting on the meaningfulness of their new knowledge.

Personal constructivism drew on the personal construct theory of two cognitive psychologists. George Kelly's personal construct psychology emphasizes the role of "personal construction" in the development of both scientific community knowledge and children's attempts to make sense of their experiences of the world. David Ausubel's theory of cognitive learning argues that meaningful learning involves building on learners' prior knowledge or existing mental constructs. Both models of learning focus on concept development rather than on Piaget's generalized cognitive structures or "content-independent" forms of thought.

The popularity of personal constructivism owes much to its neat fit with the content of science curricula, providing prescriptive means for teaching more effectively the knowledge base of school science. In the hands of science educators, personal constructivism has inspired a range of research and teaching methods for monitoring students' conceptual profiles and facilitating the process of meaningful learning, especially by means of inducing cognitive conflict. Well-known methods include "concept mapping," "interview about instances and events," "predict-observe-explain," and "two-tier diagnostic tests."

However, controversy surrounds the term "misconceptions," with many arguing that it is not a good constructivist teaching practice to regard as misconceived (i.e., wrong) students' intuitive conceptions when they do not accord with canonical science. A deficit view of students' prior knowledge can lead to a didactic teaching approach in which the teacher's knowledge is imposed on the basis of his/her authority, eliciting little more than rote learning and social conformity among students. A preferred term is the more respectful "alternative frameworks." Controversy also surrounds the constructivist agenda of conceptual change when it is used as an "ideology replacement therapy" for students whose worldviews do not necessarily accord with the Western modern worldview, especially children of indigenous populations (see critical constructivism below for more on this issue).

Radical Constructivism

Ernst von Glasersfeld's radical constructivism was thrust into the limelight by science educators dissatisfied with the objectivism of personal constructivist pedagogy, where objectivism entails a naïve realist "correspondence theory" of truth, which regards scientific knowledge as an accurate depiction of physical reality. Radical constructivism draws on Piaget's lesser known background theory of "genetic epistemology" which emphasizes the inherent uncertainty of the constructed knowledge of the world by all cognizing beings, from children to scientists. According to the defining principle of radical constructivism, cognition serves an adaptive purpose inasmuch as it organizes our experience of the world, rather than enables us to "discover" an objective ontological reality. This is not to deny the existence of external reality, a world of physical things that we can sense, just that we cannot peer around our conceptual frameworks and see it directly in an unmediated or pure sense. Furthermore, from a proof-of-concept perspective, we do not have access to an objective "God's eye" standpoint from which to judge the match between the so-called essence of external reality and our cognitive constructions. We are, therefore, restricted to "dancing" with the shadows on the wall of Plato's cave, the shadows of our own taken-as-shared experiential realities. Thus, our knowledge can only be judged in terms of its "viability," or fitness, for representing or modeling the physical world. For radical constructivism, the cornerstone concept of "objectivity" is reconceptualized as consensual agreement by scientific communities of practice. This instrumentalist perspective on knowledge production and legitimation is in close accord with David Bloor's "strong program" of the sociology of science knowledge (SSK) and with the philosophy of science of Thomas Kuhn who argued persuasively that scientific knowledge is "paradigm bound."

Radical constructivism directs science educators to facilitate students' epistemological understanding of the nature of science, especially the inherent uncertainty and confidence limits of scientific knowledge. A legacy of earlier science education is the naïve view that science generates absolute truths about the workings of the physical universe. As a result, many "well-educated" people reject the Intergovernmental Panel on Climate Change report (IPCC 2013) that climate change is human induced. The skeptics are not happy with a finding (i.e., consensus by the scientific community) that is expressed "only" at the 95 % level of probability. This public controversy raises the question of how well science education enables students to understand the social and cognitive processes of scientific modeling. It also raises the question of how well science education enables students to understand the epistemological status of scientific concepts, theories, and laws (and to be able to differentiate between them). A naïve belief in the permanence and immutability of scientific knowledge can breed arrogance among "true believers" that debate with the skeptics is unnecessary; it is not uncommon to hear science educators claim, for example, that Darwin's theory of evolution is unassailably right and creation science is simply wrong, end of story! The tendency of science education to reproduce the ideology of "scientism" has been challenged by critical constructivism.

Within the science education constructivist movement, a "paradigm battle" between radical and personal constructivists broke out, with vociferous opposition evident in international conferences. Radical constructivists labeled (somewhat pejoratively) the objectivist standpoint of personal constructivists as "trivial constructivism," with the latter countering that the idealism of radical constructivism leads to rampant relativism. This battle was part of the larger war in educational research between the opposing epistemological armies of positivism, with its quantitative epistemology of objectivism, and interpretivism, with its qualitative epistemology of social constructivism. Another critical view of radical constructivism, articulated by social constructionism, is that it perpetuates the subject-object dualism of subjective idealism, rendering the individual mind as primary and failing to explain adequately the intersubjectivity of the social world.

Radical constructivism does not stand alone as a theory of learning; it works best in conjunction with social constructivism to support inquiry learning.

Social Constructivism

Social constructivism entered the pedagogical arena drawing on theories of social psychology such as the "socially situated cognition" of Jean Lave and Etienne Wenger, which recognizes that people co-construct meaningful knowledge in communities of practice, and the "social activity theory" of Lev Vygotsky, which identifies the essential co-development of language and thought. Social constructivism extends the "psychologistic" focus on the mind of the individual learner of both personal constructivism and radical constructivism, recognizing that learning is also a social process. A social constructivist perspective directs teachers to situate learning activities in the context of students' out-of-school lives, thereby enhancing the meaningfulness of learning science. Applying science to contexts that are familiar to students, such as testing water quality in a nearby river or monitoring energy use within the home, gives science a perceived relevance that is often missing when it is confined to the school laboratory or textbook.

In the 1990s, pioneering mathematics educators Grayson Wheatley and Paul Cobb developed pedagogies of problem-centered learning and inquiry mathematics, respectively, based on the principles of radical and social constructivism. What these approaches have in common is a perspective that students should be engaged in learning environments that allow rich inquiry-based dialogue within small groups and at the whole-class level, facilitated by the teacher. Students learn to construct explanations and justifications of their reasoning, share and negotiate with other students and the teacher, and develop the patterns of discourse of a community of mathematicians. For the teacher, eliciting students' multiple solution methods is more important than students obtaining "the correct answer" by following (robotically) a standard procedure. The teacher exercises his/her authority to legitimate students' solution strategies and does so indirectly by stimulating students to reflect critically on their assumptions and chains of reasoning.

For science education, social constructivism emphasizes the importance of engaging students in classroom discourse in order to develop the "social capital" of science (i.e., values, knowledge, skills, language), especially scientific ways of reasoning and negotiating to reach consensus in a community of practice. Engaging in discussion, whether it be teacher-directed whole-class question-and-answer or student-directed small-group work, gives students opportunities to put language to their ideas and test their viability against the ideas of other students. Peer learning is a powerful socializing process, involving a strong emotional relationship with significant others. Contributing actively to classroom discussion or listening actively to other students' questions and responses can help develop the metacognitive skill of reflective thinking (i.e., thinking about one's own thinking) which is an important step towards developing an ability to assess the viability of one's own prior knowledge and developing concepts. In collaborative learning, especially in small groups, students have opportunities to develop social inquiry skills, including active and empathic listening, learning to "take turns" in speaking, offering strategies for investigating a problem or issue, and negotiating a consensual solution or conclusion to their scientific inquiries.

The invisible frameworks that restrain teachers from creating vibrant social learning environments gave rise to critical constructivism.

Critical Constructivism

The next articulation of constructivist theory involved an extension into the cultural-political realm. Science educators sensitive to issues of social justice, such as Joe Kincheloe, were inspired by various social theories, including Peter Berger and Thomas Luckmann's theory of the "social construction of reality," Jurgen Habermas' critical social theory of "knowledge-constitutive interests," and Paulo Freire's "pedagogy of the oppressed." These social philosophers explained how the construction of socially sanctioned knowledge, such as science, is framed by powerfully invisible (i.e., hegemonic) value systems embedded in society's social structures that serve the interests of dominant sectors of society while disenfranchising others. From this perspective, science is a cultural activity, rather than being transcendental of culture, and thus, many sciences exist around the world, grounded in a variety of communities of practice (e.g., Masakata Ogawa's "multi-sciences perspective"). Critical constructivists argue that science educators, blind to this perspective, perpetuate oppressive ideologies lurking (like Trojan horses) in science curricula and assessment systems. By means of politically naive teaching methods, such as a narrowly conceived conceptual change approach, science teachers inject (unwittingly) into students' "cultural DNA" distorting ideologies such as scientism, masculinism, and Western imperialism. Cultural anthropologists describe this process of socialization as "enculturation" or "one-way cultural border crossing."

From a critical constructivist perspective, Western modern science is but one form of science, albeit the dominant form, that thrives in concert with modern technological developments and capitalist market economies to fuel twenty-first-century globalization. For postcolonial scholars, the culturally blind, one-size-fits-all Western modern science curriculum export industry is tantamount to neocolonialism. Although studies of the cultural history of science reveal that Western modern science owes much to earlier developments in Africa, China, Japan, India, Persia, and Arabia, little of this history is included in science curricula. Critical constructivism recognizes that science learning is situated in a cultural context of historical and political considerations. The science learner's construction of his/her social capital is recognized as a complex intercultural process involving the reconstruction of children's cultural identities. If science education is to become culturally inclusive, in a global sense, it cannot afford to ignore the potential "collisions" between the starkly contrasting worldviews of Western modern science and culturally different others. The mutually beneficial process of "acculturation," or intercultural borrowing, should not be left to chance.

Critical constructivism points out that science educators are deeply implicated in values education inasmuch as they are preparing future citizens to participate in their societies, not only as professional scientists, engineers, and mathematicians but also as community-minded citizens who have a stakeholding in the survival of the life-support system of the planet. It is essential, therefore, that we enable science students to develop higher-level abilities (e.g., Derek Hodson's "critical scientific literacy") such as critical reflective thinking, communicative competence, and a social conscience. These abilities and habits of mind are essential for participating in social decision-making about the ethical use of innovations in Western modern science and technology for resolving global crises such as climate change, pollution of the means of supporting life, loss of biocultural diversity, and so on, much of which has resulted from humanity's past misuse of science and its technological products. Critical constructivism calls for "socially responsible" science education.

An Integral Perspective

As science educators, how do we resolve these philosophically and politically contrasting views of constructivist theory? And how do we avoid turning constructivist theory into yet another privileged ideology that restricts science educators' evolving theories of teaching and learning? What is clear from this short history of constructivism in science education is its adaptability to a range of agendas driven by a variety of interdisciplinary interests. What emerges is an image not of a many-headed monster threatening the unwary (the Hydra of Greek mythology) but a multidimensional hologram that integrates a range of discrete images into a coherent and complex whole (for more on this, see Steffe and Gale 1995). To change metaphors, we can choose to be like the proverbial blind men and the elephant, each one identifying only one part of the whole, or we can choose to embrace the whole, making use of powerful synergies as we integrate the parts.

The power and adaptability of constructivist theory lies in its central metaphor – constructed knowing – which enables us to see ourselves as dynamic professionals undergoing constant reconstruction as we embrace and test the viability of diverse ideas. Dialectical reasoning is the catalyst that enables us to hold together in creative tension these competing and contradictory ideas, thereby immeasurably enriching our professional repertoires (e.g., Willison and Taylor 2006). But this is not to say that multidimensional, or integral, constructivism is the only game in town. Clearly there are a host of other theories about teaching and learning, including behaviorism, that are available to us now or that will emerge in the future. From a dialectical perspective, these too can be integrated into our ever-expanding repertoires.

As science teachers, at times it might make good sense to engage students in memorization and rote recall, and at other times, we might want to correct a common student misconception or enhance students' epistemological understanding of the nature of science or direct students to explore collaboratively indigenous knowledge systems or investigate the historical roots of contemporary scientific theories; and we might want to engage students in debate or role play or theater production or community projects and so on. All of this is possible; nothing is excluded by virtue of ideological conflict. The critical factor in choosing a teaching and learning strategy should be the professional judgment of the epistemologically astute science teacher as to which theory of knowing (or epistemology) is most appropriate for achieving a particular curriculum goal at a particular point in time.

As the past 50 years has shown, constructivist theory is adaptable to many science teaching and learning scenarios, not in a simplistic sense as a method of teaching and learning but, as explained by Tobin and Tippins (1993), as a powerful epistemological "referent" that enables teachers to think creatively about how to make learning science more motivating, memorable, and meaningful, no matter the number or mix of students or the quality of available resources or the constraints of the curriculum and examination system. If the challenge of engaging students in deeply meaningful learning seems too great for science education alone, then interdisciplinary collaboration offers an exciting pathway for school-based development and implementation of integrated curricula.

Cross-References

- ▶ Alternative Conceptions/Frameworks/Misconceptions
- ▶ Ausubelian Theory of Learning
- ▶ Conceptual Change in Learning
- ▶ Constructivism: Critiques
- ▶ Piagetian Theory
- ▶ Prior Knowledge
- ▶ Social Epistemology of Science
- ▶ Socio-Cultural Perspectives and Characteristics
- ▶ Sociology of Science
- ▶ Transformative Science Education

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Constructivism: Critiques

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There are three essential lines of criticism of constructivism in the literature:

1. That the constructivist perspective is indistinguishable from “discovery learning”
2. That the constructivist theoretical perspective is essentially attempting to make something out of a triviality
3. That the constructivist perspective has little or nothing to say about the nature of an effective pedagogy

Each of these is now discussed in turn.

Criticism 1: The Constructivist Perspective Is Indistinguishable from “Discovery Learning”

Central to the basic critique of those who see constructivism as a form of discovery learning is a questioning of the constructivist belief that all knowledge has to be personally constructed. The inference made by these critics is that constructivists believe that knowledge constructed by the students themselves is more valuable than knowledge which is modeled, told, or explained to them; for instance, advocates of discovery learning very commonly concur with Piaget’s assertion that “each time one prematurely teaches a child something he could have discovered for himself, that child is kept from inventing it and consequently from understanding it completely.” These critics also argue that constructivists believe that students are more likely to apply and extend that knowledge than those who receive direct instruction. Furthermore, there are some notable studies that provide evidence that purport to show that learning by direct instruction is more efficient than discovery learning. Hence, the empirical evidence contradicts the premises of constructivism. However, the model of discovery learning consistently used within this research was one where the students were simply left to discover, in a totally unguided manner, the role of the control of variables strategy in scientific investigation. Leading constructivists, such as Rosalind Driver, have pointed explicitly to the need for an “input from the teacher” and see teaching as a process of negotiating meaning. Adopting a constructivist perspective on learning does not mean, or even imply, that the child is left to reinvent, in a very limited period of time, what has taken very bright people years to create. Thus, this critique is overly simplistic and has erected a straw man – in short a vision of constructivist pedagogy which very very few constructivists hold.

Matthews (1993) offers a somewhat related but more philosophical and more sophisticated critique of constructivism. He argues that constructivists subscribe to a view that sees all knowledge as grounded in sense impressions or experience. Drawing on Hanson’s notion that all observation is theory dependent – that is, what we perceive is determined by our prior conceptions – Matthews argues that scientific ideas are abstractions of reality where phenomena are idealized, e.g., frictionless planes, point masses, and the absence of air resistance. Such ideas are not born of sense impressions but by imagining the world not as *it is* – but as it *might be*. If anything observation is an obstacle to the development of the scientific idea. For instance, observation would lead to the construction of an explanation for day and night being caused by a moving Sun rather than a spinning Earth. Therefore, constructivism is correct in stressing the invention of the theoretical ideas of science but flawed if it thinks that these can be developed solely by empirical investigations of the material world. Statements that science should be an attempt to "make sense" of the living world are not helpful as scientific advances commonly involve a "commitment to propositions that literally defied sense." Matthews essential criticism then is that what constitutes science is a set of ideas or theoretical propositions. These are not lying around to be discovered but must be explicitly introduced to children, and this requires the teacher to be competent in the subject in which they teach and accountable for presenting the commonly accepted knowledge in that domain.

While most people would agree with the details of Matthews' argument, the problem with his case is that he has equated "constructivism" as having a commitment to the pedagogy of "discovery learning." This is not so and nowhere do constructivists make such a commitment. Rather, in science education most of constructivist pedagogy has been guided by Ausubel's seminal statement that if he had to reduce the whole of educational psychology to just one thing, it would be that "the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" (Ausubel 1968). So widely cited has this statement become that it has required the status of a mantra for constructivists. Notably though, it makes no statement about the nature of the teaching that would be appropriate.

Discovery learning, in contrast, is based on a set of pedagogic commitments about how students should learn and be taught. The term "discovery learning" has been used in a quite wide range of ways and contexts. At the heart of these multiple usages is reference to a curriculum where students are exposed to particular questions and experiences in such a way that the designers suggest that students "discover" for themselves the intended concepts. However, the experiences and activities are carefully selected by the teacher to help reveal the ideas that are considered important. In that sense, the "discovery" process is very guided. Those who hold a view that teaching is a process of discovery see teaching and learning as an uncertain and contingent process. Curriculum in that sense is largely determined "in the moment" and emergent through a process where the teacher guides students with activities that are largely responsive to their students' ideas and the classroom discussion. Thus, discovery learning is essentially a contingent experience and a set of pedagogic commitments about how students best learn. Constructivism, in contrast, is a set of epistemic beliefs about how individuals come to know and it is not legitimate to equate the two. Thus, while Matthews makes salient points, his and others' critiques based on comparisons of constructivism with discovery learning essentially founded on a misconstrual of the pedagogic beliefs of constructivists.

Criticism 2: Constructivism Attempts to Create Significance from a Triviality

The second critique mounted against constructivism is that the basic tenet, captured by the Ausubelian mantra, is little more than a truism. Most people would agree that humans are born with some innate capabilities for conceptual and linguistic processing and that these develop through acting on the world and through social interaction. However, by and large much of what we commonly term to be knowledge – whether it be public or personal knowledge – is *constructed.* It cannot be acquired by a process of simply telling. Rather we all have to construct an understanding of something we are told. For instance, if you ask somebody for directions to the nearest train station, as they explain the route, in your mind you run a mental picture of the route to be walked constructing a mental map to retrieve shortly. Failure to do this means that the information does literally go in one ear and out the other. Thus, the only reasonable inference that can be drawn from Ausubel's dictum is that the construction of knowledge must be an active process even if the learner is simply listening to a lecture. Nothing will be understood and no change will occur in the individual's conceptual structures unless the learner makes a cognitive effort to assimilate the information presented. What then is the insight provided by constructivism?

The Ausubelian mantra clearly has value in reminding the teacher that the lens through which all new ideas are filtered is the existing set of knowledge and concepts that the student holds. As such it is essentially nothing much more than a statement of common sense (Osborne 1996). Yes it has value as a theory for reminding teachers that students' existing ideas are the foundations on which new ideas must be laid – but it has no predictive validity. Another criticism of this tenet is that it fails to acknowledge the social nature of knowledge construction. All knowledge can be seen as a product of a dialectic between construction and critique. While it is possible for the individual to engage in this process, most knowledge is generated by engaging in dialogue within a community. All scientific knowledge, for instance, is the product of an ongoing social interaction between scientists. Within that community, hypotheses are proposed, experimental designs are developed, and data are collected. A disposition to circumspection within the community means that only those ideas found not to be wanting survive to a later day. Argument from evidence is, therefore, very much a core practice of science. Strangely, however, it is notable by its absence in the science classroom. The constructivist overemphasis on the need to engage in construction, be it personal or social, has neglected the role of critique in helping students to identify flaws in their own thinking and generate dissatisfaction with their existing mental schemas.

A considerably body of evidence has now accrued that the learning of new concepts is essentially best done through social interaction with others where ideas are tested and challenged. In a meta-analysis of a range of studies on learning, Chi (2009) categorized activities on a continuum from passive (listening only) to active (any activity requiring physical activity) to constructive (the production of a physical artifact that transcends what was given to the student) to interactive (where the learner engages in dialogue with a partner). Her analysis shows that this hierarchy is supported by the empirical findings of research, with interactive being the most effective. Interactive approaches to learning force students to justify their views by constructing explanatory justifications for their views. In one study, for instance, students were instructed to explain to a partner what a text really said. Their interaction generated a large number of critical questions, something which is a feature of generative dialogue helping students to identify why the wrong answer is wrong as much as understanding why the right answer is right.

Criticism 3: Constructivism Has Little or Nothing to Say About the Nature of an Effective Pedagogy

Issues such as those discussed immediately above raise the third criticism about constructivism, that "a weak or at least a controversial epistemology has become the basis for a strong pedagogic policy" (Phillips 1995, p. 11)). The primary influence underpinning much of the theoretical commitments of constructivist pedagogy was a highly influential paper written by Posner et al. (1982). This paper, which drew heavily on Thomas Kuhn's work on conceptual development in the sciences and the structure of scientific revolutions, argued that learning was a process of conceptual change where prior conceptions were replaced by new conceptions if there was first initial dissatisfaction with existing ideas, and then if the new idea was "plausible," "intelligible," and "fruitful." Posner et al.'s argument was that for learning to occur, there must be a change in the student's conception, albeit gradual and piecemeal, such that there is a substantial reorganization and change in the conceptions held by the student. The problem is that there is little empirical evidence to support this view. In one of the most systematic examinations of conceptual change within young students, other research suggests that most students undergo a process of "weak restructuring" of their knowledge or "belief revision." Hence, the idea that any form of pedagogy could overturn or displace an existing conceptual schema rapidly was flawed. Rather students undergo a process of assimilation or accretion in which ontological categories are increasingly differentiated or in some cases coalesce.

Another view, developed by the psychologist Guy Claxton, goes further and argues for a triadic view of the nature of the conceptual schemas that people have for the material world. At one level, there is what he terms "gut science" which is the kind of tacit and intuitive knowledge we use to make calculations about whether it is safe to cross the road. Then there is the kind of overt knowledge which he characterizes as lay science – the kind of knowledge which is simply a commonsense interpretation of the world such as the idea that heavy things sink, light things float or that a force is needed to sustain motion. Such common sense knowledge is functionally effective for many everyday situations. Finally there is formal scientific knowledge which is the focus of what is taught in school and necessary for working within the scientific community. He argues that individuals use all three forms of knowledge and switch readily between them.

A further critique of Posner et al.'s theoretical framework is that their model is overly rational in focusing on student cognition without any consideration of the way in which students' motivational beliefs might affect the outcome of any learning experiences. Rather, students' cognition is heavily influenced by a set of four general motivational constructs that are their learning goals, the values they hold, their beliefs about their own self-efficacy, and their beliefs about the locus of control. In the case of the latter, for instance, whether they think that intelligence is fixed or mutable and dependent upon the effort they are prepared to make. The failure to consider any of these aspects within the writings on constructivist approaches to teaching is indicative of a theory which has failed to recognize that there is a significant affective component to successful learning.

Perhaps the most substantive criticism of constructivism is that as a theory of learning, it has little to say about teaching beyond the requirement to ascertain students' prior knowledge. Granted its message is that the learner must be active if they are to construct an understanding of scientific concepts, and granted that the argument of social constructivists would be that dialogue with others is essential if ideas are to be developed and comprehended. However, what are the instructional strategies and mechanisms that will generate conceptual change? Most constructivists borrow from Posner et al. and argue that the essential mechanism for generating conceptual change is conceptual conflict. For instance, if students believe that heavier things fall faster, that idea should be challenged by asking them to make a prediction and explain why they believe this. The phenomenon can then be demonstrated with a bunch of keys and a scrumpled piece of paper will both fall at the same rate. The disparity between their prediction and their observation generates conceptual conflict and forces revision of their concepts. Rosalind Driver, in her writings, argued that students should be exposed to conflict situations such as these and then constructed new explanations. But beyond the need to engage in small group work and discuss their ideas, little argument is offered about what might constitute an effective educational strategy. One exception to this is the work of Gunstone and White who developed the notion of predict-observe-explain as an instructional mechanism to generate conceptual conflict. However, even then, while undoubtedly an effective teaching mechanism, it offers no guidance about content. In contrast, neo-Piagetian theory does offer a framework for the selection of content and an argument for the nature of age-appropriate instructional activities. Likewise, those concerned with literacy in science do have a theory which drives what kinds of activities are needed to develop students ability to read and write science – essentially the idea that reading in science must be reflexive which requires tasks which are analytical where the text is summarized in either tabular or diagrammatic form or restructured by reassembling text to make meaning.

In Conclusion: Looking Across the Three Areas of Criticism of Constructivism

What is missing from constructivist writing then is an account of the processes that would support learning and a rationale for their justification. The point that Matthews is making is that if you want an individual to see the world in a new way, then they must be introduced to that way of seeing. Anybody who has tried to get students to observe a specimen down a microscope knows this. Students will not see what you see unless they are given an a priori conception of what to see. The teacher is thus reliant on the use of metaphor and analogy drawn from the familiar world of the student to help them "see" the scientific idea. Ultimately, the failure of constructivism is a failure to recognize the fact that most scientific ideas are unnatural – they do not make sense. Who in their right mind would ever come to the view that atoms are mainly empty space, that day and night are caused by a spinning Earth, or that we look like our parents because every cell in our body contains a chemically coded message about how to reproduce ourselves. Not surprisingly then, it is not immediately obvious how such ideas are fruitful let alone plausible when the standard misconception seems to be a more accurate description of the way the material world behaves.

What the constructivist perspective has been very successful at is challenging the notion that the child is a tabula rasa. The enormous body of research conducted in the last two decades of the twentieth century has shown that students do develop ideas about the material world from simply being in the world and acting on it. In that sense it has undoubtedly been helpful – for to teach any students something about science, constructivism shows that not only is it necessary to know something about science, but we also need to know something about the child. Moreover, in placing the emphasis on the need for learner to be active, it has helped to challenge the notion that simply presenting information in a clear and effective manner is the essential basis of good teaching. Indeed what much of the research in this paradigm has repeatedly demonstrated is that, contrary to the popular view that most communication is a simple act with failure being a rare event, most communication is actually a complex act with *success being the exception*. However, constructivist research has little to say about the selection or sequencing of content, how to build students capability to be metacognitive, or a rationale for any specific instructional strategy and its selection. Any theory which fails to help teachers make rationally defensible professional judgments for what they do is in essence an ideology. For a profession which desperately needs empirically tested theoretical arguments for the instructional choices that teachers make on a daily basis, the argument here is that constructivism is to be found wanting. That is not to say that there is no value in it – rather that the reader should be aware of the limitations as well as its much promoted strengths.

Cross-References

- ▶ Alternative Conceptions/Frameworks/Misconceptions
- ▶ Argumentation
- ▶ Conceptual Change in Learning
- ▶ Constructivism
- ▶ Dialogic Teaching and Learning
- ▶ Discourse in Science Learning
- ▶ Discovery Learning
- ▶ Socio-Cultural Perspectives on Learning Science

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Context of Discovery and Context of Justification

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Keywords

Context

Introduction

How scientists come up with new ideas, concepts, hypotheses, and theories is usually different from how they present and argue for them in published research articles and textbooks. Philosophers of science have conceptualized this difference into a more rigorous distinction between the context of discovery (for generating novelties) and the context of justification (for validating them). This distinction is also often aligned with the distinction between the descriptive (how science actually works) and the normative (how it ought to work).

History of the Discovery–Justification Distinction

With the development of the new sciences in the early modern period, philosophical discussions on scientific discovery arose in attempts to establish the scientific method. Francis Bacon (1561–1626) and René Descartes (1596–1650) offered the most prominent philosophical models among others to explain and encourage scientific discoveries. Their ideas, inspired by the emerging new scientific practices, in turn prompted groups of natural philosophers to embark on making new findings especially through concerted efforts via newly founded scientific societies. For Bacon, knowledge was gained securely through an inductive process, starting with the collection of unbiased observations and progressing toward more theoretical generalizations. For Descartes secure knowledge could only begin from indubitable foundations, from which the rest was logically deduced. In either the Baconian or the Cartesian view of ideal knowledge, there was no explicit distinction between discovery and justification, as their belief in the existence of the "scientific method" was supported by the conviction that the best method for making new discoveries was at the same time the best justification of the discoveries.

This conviction, however, was put to question starting from the early nineteenth century. An alternative view of scientific discovery, popularly captured by the "Eureka" moment and reinforced by the Romantic image of the scientific genius, made it difficult to conceive that there could be any fixed method for discovery. On the other hand, appreciation of the use of hypotheses in scientific practice paved the way for the rise of hypothetico-deductivism, which argues that the scientific method only concerns the testing of hypotheses, regardless of how they are conceived (Nickles 1980, Chap. 6). These developments drove a wedge between discovery and justification, culminating in the categorical distinction between scientific discovery and scientific justification by leading empiricist philosophers such as Hans Reichenbach (1891–1953) and Karl Popper (1902–1994) in the first half of the twentieth century. According to Reichenbach, the "context of discovery" is subject only to psychology, which deals with the processes of thinking as they actually occur. While any scientific theory consisting of a group of propositions can be justified by being in a correct logical relationship with observational statements, the discovery process was not amenable to this sort of "logic" for philosophers to seize upon. (Thus, there is a great irony in the English title of Karl Popper's masterpiece in the philosophy of science, *The Logic of Scientific Discovery*; there is no similar irony in the original German title, *Logik der Forschung*). Discovery is a subject of all kinds of empirical research, historical, sociological, and psychological. Epistemology is and should be confined to the "context of justification," in which the propositions produced in science are reformulated and rearranged so that their structures and logical relations are made explicit. Epistemology thus considers a rational reconstruction of scientific practice, rather than the actual practice of scientists. The "context distinction" between discovery and justification has exerted a deep influence on philosophers of science through the century (Nickles, Chap. 1).

The terms of debate began to change again, however, with the demise of the orthodoxy in Anglophone philosophy of science that was the legacy of the logical positivism of the Vienna Circle. For post-positivists such as Thomas Kuhn (1922–1996) and Paul Feyerabend (1924–1994), it is theories that give meaning to observations, not the other way around (Chalmers 1999, Chap. 8). Therefore, any truly novel discovery, even of facts, can take place only if it is directly tied to theoretical change. During a phase of "normal science," in which the ruling paradigm is not challenged, facts can pile up more or less cumulatively, and theories are improved only in a trivial way; hence, there is no philosophical problem about justification or discovery. But in the process of a scientific revolution, new theories and facts are discovered together because facts can only be assigned their meaning by underlying paradigmatic theories. Therefore, such discovery, according to Kuhn, is not a matter of a "Eureka" moment, but a difficult protracted process of adjustments of establishing paradigms and their relevant facts together that need to be agreed upon by a whole scientific community and then passed on to the next generation through laborious pedagogical efforts (Schickore and Steinle 2006, Chap. 7). Justification only happens through such processes of negotiation, in which Kuhn famously declared that there is no higher standard of judgment than the assent of the relevant scientific community. Kuhn's stance not only upset the traditional philosophers due to its anti-rationalistic implications even for the context of justification, but it also brought justification and discovery back together, this time in an untidy mix.

The emphasis on the social processes highlighted by Kuhn in his discussion on scientific discovery has been fully adopted and extended by social constructivists. Historians and sociologists of the constructivist bent have offered instructive case studies revealing diverse disagreements and complex negotiations among self-claimed discoverers and their allies or followers, and their political, social, and professional agendas with respect to the "authorization" of discovery. As shown in the classic case of the "rediscovery" of Mendel, scientific discovery in the social constructivist picture is a retrospective affair, a product of a discussion among relevant practitioners in a given discipline; a discovery as an achievement, its meaning, and its discoverer, it is argued, can only be retrospectively evaluated and acknowledged. In these social constructivist construals of scientific discoveries, the scientific realist commitment which implicitly underlay the traditional philosophical discussions has been explicitly problematized and severely attacked. There are various types of antirealists in this debate (Chalmers 1999, Chap. 15; Psillos and Curd 2008, Chap. 21): constructivists often draw on Kuhn's notion of incommensurability, while a majority of antirealist philosophers base their arguments on skepticism or agnosticism about unobservable entities, as in the philosophy of constructive empiricism advanced by Bas van Fraassen (1941–). What these antirealists have in common is that they do not take the notion of discovery for granted, as they reject the realist connotation implied in the term (if something has been "discovered," it must really exist). For them it is meaningless to distinguish sharply between discovery and construction, both being processes of finding a solution to a problem or contriving an empirically adequate theory to save the phenomena.

Discovery and Justification in Practice

With the long-lasting belief that there are some genuine methods for scientific justification (even if no simple logical algorithms), philosophers of science have principally explored its different strategies and procedures largely under the rubric of confirmation theory: inductivism, hypothetico-deductivism, Bayesianism, and value-laden comparative theory appraisal (Psillos and Curd, Chaps. 10, 11, 28, 31, 47). Yet, with the recent rise of a more practice-oriented view of science, it is now generally acknowledged that even justificatory practices are contingent on the context, not captured by either an ahistorical formalism with the belief in a pure observational language or a theory-dominated holism notoriously represented by Kuhn's notion of paradigms. This sensitivity to context leads us to ask in which epistemic situation a knowledge claim is justified and which method of justification can be intelligibly demanded of the knowledge claimant or rationally accepted by the relevant practitioners; this means accepting that an agent attempts to justify a scientific knowledge claim to her relevant epistemic community participating in specific epistemic activities with shared epistemic goals.

Notwithstanding the theory-ladenness of observation, for example, not all observations in practice are on a par. Some are more stabilized and robust in a relevant setting as is the case with middle-level regularities, being relatively independent of high-level theories and their changes, which could function tentatively as an empirical foundation to test and warrant a novel knowledge claim. Yet, these regularities can be made more elaborated and refined in terms of precision, scope, and the like through iterative processes. Moreover, there are various ways of testing a knowledge claim which are to be chosen by the actor depending on the relevant aims, resources, audiences, and even metaphysical values and principles. Even any plausible skepticism of induction could be avoided, for example, in a very well-controlled experimental setting which successfully removes as many extraneous non-observational hypotheses as possible. These, all in all, come down to a self-corrective and pluralistic attitude to scientific justification.

A shift of emphasis to scientific practice is more than welcome in relation to the study of scientific discovery, as traditional philosophical interest in the subject has been meager or just skeptical. Of course, it should be acknowledged that there has been considerable interest in "abduction," often equated with "inference to the best explanation," as a plausible "logic" of scientific discovery (Psillos and Curd, Chap. 18). There are even several automated discovery tools, as is well illustrated by statistical techniques and computer simulation programs to find out from given data abstract correlations or patterns or models, though it is still out of their reach to get at any deep theories or hypotheses. Yet, it would not be a surprise to see that existing philosophical frameworks are helpless when confronted with a sheer diversity of scientific discoveries in practice, given that typical philosophical discussions of scientific discovery pay exclusive attention on the discovery of theories. Therefore, it would be helpful to ask: What sorts of things do scientists discover in practice? A rough taxonomy should include theories and hypotheses, principles and laws, facts and phenomena, observable and unobservable entities, properties and processes, and the like. This again leads to another intriguing question: Are there different patterns in scientific discovery depending on what is discovered? For example, it is argued that discovering unobservable entities like electrons is inextricably interconnected with justifying their existence somehow. Here the complicated link between the contexts of discovery and justification comes up again (Schickore and Steinle, Chap. 12).

The discovery of unobservable entities illustrates that our understanding of scientific discovery would be enriched by a process model of scientific discovery. Anything that looks like a "Eureka" moment should be seen as a nodal point on a long research trajectory in ongoing interaction with the relevant research community; in this sense, the meaning of a discovery is often transformed as it is consolidated, often in ways that are not in accord with the original discoverer's own conception of it. The discovery of unobservables also links up with debates on scientific realism. Here, the descriptive task is to investigate the reason why the actors accept that something is "discovered," not "constructed" or "invented." Yet, normatively, the positions will be divided: entity realists would argue for the discovery of manipulable unobservables, whereas antirealists might recommend a skeptical or agnostic attitude toward them. One of the ways out of this impasse could be to ask again in which context the question of existence or truth is meaningful or useful. That is, we could investigate various ways of accessing reality manifested and developed in scientific practice and evaluate their ontological and epistemological implications.

Implications for Science Education

What does the discovery–justification distinction imply for science education? It seems that the distinction is implicitly but strongly present in ordinary educational settings: students are typically not taught about the process of discovery, though they are usually given some justifications for the theories they spend countless hours learning to apply. In fact they only tend to get told about discoveries if there are striking stories associated with them (e.g., Fleming's penicillin mold, Newton's apple, Kekulé's dream of snakes biting their own tails); these discovery stories are normally used to enhance the "human interest" in science, not especially to teach about real history or methodology.

One may question why we should want to teach students anything substantive about the processes of scientific discovery or justification. On the side of justification, at least many would agree that knowing how scientific justification works is indispensable for acquiring a proper critical appreciation of scientific knowledge; it is difficult to imagine how people lacking a sense of methods of justification can be competent to judge for themselves controversial issues such as policies concerning global warming, the risks associated with vaccination, or the legitimacy of including intelligent design in curricula. But how about discovery? For students who will go on to become research scientists, it is important that their habits and expectations do not become hampered by distorted or overly restrictive notions of how discovery works. Advocates of discovery learning, inquiry-based learning, and problem-based learning would go much farther to argue that going through one's own process of discovery is the best way to learn anything at all (see Schwab (1960) for an early exposition).

Cross-References

- ▶ Biology, Philosophy of
- ▶ Chemistry, Philosophy of
- ▶ Context-Led Science Projects
- ▶ Discovery Learning
- ▶ Discovery Science
- ▶ Inquiry, as a Curriculum Strand
- ▶ Problem Solving in Science Learning

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Context-Led Science Projects

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Keywords

Context; Contexts; PISA; SSI; STS; Thematic

Context-Based Science Curriculum Projects

Since the early 1970s, several science courses have been developed which could be labelled "context-based." In some areas of the world, these courses are named Science-Technology-Society (STS). The aims of such courses are usually to make science more relevant to students by linking science to contexts in personal life, local and global situations, and/or practices in science and technology. The course developers expect that this approach is motivating for students due to its focus on familiarity and relevance. Furthermore it might help students to be able to apply scientific knowledge and skills in real-life situations, such as is expected in the OECD Frameworks for Scientific Literacy of the Programme for International Student Assessment (PISA).

In practice a large variety of approaches have been developed, from a short series of lessons to full curricula, with aims which range from simply motivating students to preparing them for decision-making or social action. In some cases materials are monodisciplinary, linking specific science concepts to contexts; in other cases units deal with complex socio-scientific issues (SSI) from areas such as health, climate, and environment. Some projects have remained local, while others have extended to whole countries or have even been adapted across the world.

Most context-based science teaching materials are aimed at students in the age group 12–18. Some efforts have also been made to develop teaching materials for primary and undergraduate education.

Independent research on the effects of the context-based approaches has been limited. Direct comparison of regular and context-based approaches is difficult as aims are partly overlapping and partly different. Available review findings indicate that context-based approaches tend to result in improvement of attitudes to science and to higher quality reasoning and reflective judgments; the understanding of scientific ideas developed seems comparable to that of conventional approaches.

Examples (in Chronological Order) of Context-Based Science Projects

PLON

The PLON project (Dutch acronym for Physics Curriculum Development Project) developed between 1972 and 1986 full, context-based courses (including student's textbooks, teacher's guides, technician's manuals, and even to some extent examination papers) for secondary physics education in three Dutch ability streams. The PLON curricula were context based in the sense that the students' "life world" was taken as a starting point, with an emphasis on technological artifacts and natural phenomena in junior secondary education (grades 8–9, age 13–14), supplemented with an emphasis on socio-scientific issues and the nature of science in senior secondary education (grades 10–12, age 15–17). The aims of physics education put forward by the PLON project have evolved over a number of years into a balance between preparing students, on the one hand, for further education and/or future employment and, on the other hand, for coping with their (future) life roles as a consumer and citizen. An effort was made to find a balance between these two aims by developing teaching/learning units in which basic physics concepts and skills – covering most of the traditional content areas in physics education such as kinematics, mechanics, energy, electricity and magnetism, optics, sound, and matter – are dealt with in a personal, social, or scientific context. Hence the PLON curricula aimed at "physics for all" and not just for future specialists.

IPN Curriculum Physik

In the 1970s, a new curriculum for German school physics (grades 8–10, age 13–15) was designed by the Institute for Science Education (IPN) in Kiel. One aim was to strengthen the link between physics content and students' natural and technological environment. In some modules physics was related to technologies such as bicycles, electric cars, and cameras. Other units dealt with noise pollution, nuclear power stations, automation, and alternative energies, taking into account problems discussed in society.

Science in Society

The Science in Society Project was set up in 1976 by the UK Association for Science Education (ASE). The purpose of this upper secondary school course was to give students (age 17–18) a better understanding of the place of science and technology in the modern world and an awareness of the importance of using them wisely to assure the future of mankind. The developers took this to require an appreciation of the nature of science and a better understanding of industry, involving aesthetic, philosophical, moral, and economic considerations as well as scientific ones. The course was divided into nine units: Health and Medicine, Population, Food and Agriculture, Facts, Energy, Mineral Resources, Industry in the Economy, Land and Water, and Looking to the Future. Much of the work in the course was divergent and required teaching methods that were different from those commonly used in science lessons. Examples are project work, searching out information, reporting to the class, industrial visits, watching films, and decision-making simulation exercises.

Science in a Social Context (SISCON) in Schools

A series of eight books was published in 1983 by the UK project SISCON-in-Schools, an offshoot of the university-level SISCON project. The books provided a course in science and society for general studies at upper secondary school level (age 17–18), specially designed to make scientific problems accessible to nonscientists, as well as explaining the social aspects of science to aspiring scientists. The eight titles were *Ways of Living; How can we be sure?; Technology, Invention and Industry; Evolution and the Human Population; The Atomic Bomb; Energy: The Power to Work; Health, Food and Population;* and *Space, Cosmology and Fiction.*

SATIS

The first Science & Technology in Society (SATIS) project was launched in the UK in 1984. The materials were intended to enrich and enhance the teaching of science and designed to be incorporated into existing science programs. They did not make up a complete course but were a varied set of resource materials, to be used in a flexible manner by teachers to meet their own needs. The units were written by teachers and validated by experts. They included innovative teaching and learning activities such as role play, case studies, and structured discussion. More than 100 SATIS units were published for students aged 14–16 years by the UK Association of Science Education (ASE). In 1987 the SATIS project extended its work to 16–19 year olds with the publication of 100 units, clustered into themes such as materials, energy, environment, health, and ethical issues. More emphasis was placed on guiding the study of students while expecting them to gather the necessary information as a basis for discussion and debate. From 1989 the project also produced some materials for younger students (age 8–14).

Salters Projects

The UK Salters projects (named after an important sponsor of the projects and based at York) started in 1983 with the development of five context-based chemistry units for 13-year-old students. Subsequently a series of courses was developed, covering biology, chemistry, and physics for the high school range (age 11–18) in England and Wales: Chemistry; the Salters Approach (14–16); Science: the Salters Approach (14–16); Salters Science Focus (11–14); Salters Advanced Chemistry (17–18); Salters Horners Advanced Physics (17–18); and Salters-Nuffield Advanced Biology (17–18). Many of these courses have been adapted for use in other countries. Common design criteria for all Salters courses are that they should enhance students' appreciation of how science (1) contributes to their lives or the lives of others around the world and (2) helps them to acquire a better understanding of the natural environment. So units start with aspects of the students' lives drawing on both direct personal experience and ideas encountered through the news media. They introduce scientific ideas and concepts only as they are needed for understanding of the contexts and applications being explored. Units again suggest a range of teaching and learning activities. All courses try to combine a foundation for future studies with providing a satisfying course for those who will take the study of science no further.

ChemCom

The US Chemistry in the Community (ChemCom) project in the 1980s developed a year-long course primarily for students (age 16) who do not plan to pursue careers in science. Its purpose was to help students (1) realize the important role that chemistry will play in their personal and professional lives, (2) use principles of chemistry to think more intelligently about current issues they will encounter that involve science and technology, (3) develop a lifelong awareness of the potential and limitations of science and technology. Each of the eight modules centres on a chemistry-related technological issue, and the setting of each module is a community: school, town, region, or the world. Topics addressed are water needs, conservation of resources, petroleum uses, foods, nuclear chemistry, air and environment, health, and chemical industry. The first (trial) edition was published in 1985 by the American Chemical Society.

Chemie im Kontext

Chemie im Kontext (ChiK) has, since 1997, been a cooperative project involving teams at the Universities of Dortmund, Oldenburg, and Wuppertal and the Leibniz Institute for Science Education (IPN) in Kiel. ChiK is in the tradition of ChemCom and Salters Advanced Chemistry yet distinct from either one. While ChemCom introduces a sequence of topics without much conceptual relationship between them, Salters follows a more stringent line of conceptual development. The approach of ChiK is between these two, using contexts that are not in particularly systematic sequence, yet using them to develop a coherent set of basic chemical concepts.

The core of the project is a conceptual framework for chemistry teaching in grades 8–13 (age 13–18) in the German system of general education. The program provides teachers with guidelines, examples, suggestions, and collections of material that they can adapt to their specific needs in their particular environment by constructing their own lessons within the given framework. After this original framework had been developed by the core group of science educators, a large-scale project was undertaken (funded by the German Federal Ministry of Education) to implement these ideas in classroom practice. Regional teams of teachers were established and accompanied and supported by members of the project staff. Alternating between individual work and group meetings, the teachers produced, tried out, and reflected on teaching units that were then made available to other groups of teachers for adaptation.

The nationwide discussion in Germany in the past decade about science education standards has led to widespread adoption of the notions of basic concepts and context-orientation in the curricula of several German states.

Cross-References

- ▶ Curriculum Movements in Science Education
- ▶ Programme for International Student Assessment (PISA)
- ▶ Relevance
- ▶ Science, Technology and Society (STS)

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Contrat Didactique

▶ Didactical Contract and the Teaching and Learning of Science

Cooperative Learning

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Cooperative learning is a method of teaching and learning in which students work together in small groups to accomplish a common goal. The goal is reached through interdependent working, although students are also individually accountable for their work within the group. Cooperative learning can be used across a wide range of settings ranging from classroom to lecture, laboratory sessions, and online classes. There are five essential elements of cooperative learning:

- Positive interdependence – group members "sink or swim together"
- Face-to-face interaction – mutual support
- Individual accountability – individual contributions to the task are assessed
- Social skills – include trust-building, leadership, and decision-making
- Group self-evaluation – groups and their teacher reflect on the efficacy of the group

There are many claims from research that cooperative learning results in a higher level of student achievement, as well as social and economic benefits, than when students are engaged in competitive or individually based learning. Theories relating to how cooperative learning "works" suggest that the foundation for cooperative learning success may be explained by a combination of motivational, social cohesion, and cognitive theoretical perspectives. The most commonly reported strategy for developing cooperative learning activity in science classes is "jigsaw." In jigsaw, each group member is responsible for working on a specific task, for example, recording data. All "recorders" in the class are given specific instruction to become "expert recorders." Finally, groups carry out the activity with each member as "expert" in part of the task. Cooperative learning is distinguished from collaborative learning in that cooperative learning is highly teacher directed and more closed ended and has specific answers, whereas collaborative learning is characterized by student empowerment in working together on more open-ended, frequently complex tasks.

Cross-References

▶ Discussion and Science Learning

Critical Issues-Based Exhibitions

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Controversial exhibitions; Critical exhibitions; Informal science education; Socio-scientific issues

Introduction

Historically, science centers and science museums have emphasized cultural heritage through artifacts, collections, object displays, and curiosity cabinets – extolling the wonders of science to the public. Over time, however, exhibitions have evolved to include more hands-on components. Visitors interact with exhibits, by a combination of manipulating, reading, pushing, pulling, and generally using their senses. Information is typically structured through engaging, interactive displays.

A number of different typologies for mapping exhibitions have been proposed by researchers. For example, Wellington (1998) describes two types of exhibits (that are not mutually exclusive) usually found at the science center: experiential and pedagogical. The experiential exhibition allows the visitor to experience, and perhaps interact with, phenomena (e.g, soap bubbles, whirlwinds, water vortices, and air or water movements), while the pedagogical category actually sets out to teach something (e.g., positions of organs in the body, separation of dyes by chromatography, or reflection of light). These two types of exhibitions reflect a more dominant traditional way of (re)presenting science focusing on principles, phenomena, theories, and concepts. Little attention is paid to the status or generation of knowledge or the messiness of science – in other words, science is presented to the public as neutral, authoritative, and void of context. However, in recent years, informal science settings have witnessed increased attention to issues in science and technology and consequently have attempted to develop contemporary science and technology installations with all the social and political trappings of the day. This has led to the emergence of a third category – critical exhibitions (Pedretti 2002).

Critical Exhibitions

Critical exhibitions challenge politically safe, sterile, and authoritative images of science and technology usually encountered in science centers and museums. They acknowledge the tentativeness and purposefulness of knowledge creation and negotiation and view science as a human and social activity (i.e., they address nature of science (NOS) perspectives). For example, the exhibition *A Question of Truth* at the Ontario Science Centre is designed to examine several questions about the nature of science, how ideas are formed, and how cultural and political conditions affect the actions of individual scientists. The exhibition questions the nature of scientific truth and attempts to demonstrate how science is influenced by the cultural, personal, and political backgrounds of the practitioners, qualities that include bias, and points of view.

Most critical exhibitions are issues-based and explore complex relationships across science, technology, society, and environment (STSE), inviting visitors to consider issues from a variety of perspectives with an emphasis on involvement, activity, and ideas. These thought-provoking exhibitions are developed in an effort to represent science in context and to engage the public with issues (such as reproductive technologies, climate change, genetic engineering, and mining) that are important to our lives, to the environment, and to our well-being. For example, consider recent installations such as *Energy Tracker* presented at the Miami Science Museum in Florida that encourages the public to critically reflect on energy use and renewable sources. The Smithsonian Natural History Museum presents evidence for evolutionary theory in The David H. Koch Hall of *Human Origins: What Does It Mean To Be Human?* and von Hagens' travelling exhibition *Body Worlds* pushes boundaries using human cadavers to display issues related to health and well-being. Issues-based (or socio-scientific) exhibitions create possibilities for visitors to explore the intersections across science and society and to engage with the messiness of science that stems from social, political, ethical, and historical factors.

Critical exhibitions share common characteristics: they often cut across science, technology, society and environment (STSE), address nature of science perspectives (NOS), raise public awareness about issues, consider multiple points of view, personalize science, connect science and social responsibility, teach about participation and decision-making, encourage people to be active commentators on matters related to science and technology and to be agents of change, offer a forum for discussing and debating issues in society, provide more robust views of science, and encourage healthy public debate about controversial topics.

Courting Controversy

Critical exhibitions are usually controversial in nature due in part to their interdisciplinary subject matter and the coupling of science and ethics. Consider, for example, reproductive technologies, the use of stem cells, health-related research, space exploration, or evolution. Such issues are typically contentious, fraught with ambiguities, and subject to multiple perspectives. Individuals may interpret the same information differently, and reasoning based on science alone may not be enough to resolve the conflict. Controversial issues draw upon different players; stimulate analysis of the construction and deconstruction of facts and theories; draw attention to the social processes of science and how knowledge is negotiated and utilized; and involve struggles over meaning and morality, distribution of resources, and power and control (Delicado 2009; Macdonald 1998; Nelkin 1995). They often raise tensions between individual needs and community priorities. Controversial issues can spark intense and passionate responses from people and involve problems in which different individuals and groups support conflicting courses of action.

Future Directions

It is widely acknowledged that museums and science centers avoid controversial issues. They are difficult to mount, there is an underlying assumption that public institutions are in the business of transmitting science, issues can change quickly, and funding and patronage concerns arise. Future research agendas include questions such as the following: What kinds of exhibitions are appropriate for public consumption? What ethical concerns are raised? What tale(s) do we tell? Whose stories are silenced? What is the role of advocacy? What is the role of funding? How are different viewpoints presented? Furthermore, research should consider the forms of scientific communication that are most meaningful and valuable to the public and how critical exhibitions encourage and develop meaningful public engagement with complex socio-scientific issues.

Cross-References

- ▶ Museums
- ▶ Visitor Studies

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Cross-Disciplinary Concepts and Principles in Science, Assessing Understanding of

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Assessing Cross-Disciplinary Ideas

Certain ideas expressed as principles or as concepts have explanatory power in all science disciplines. In the science education literature, these ideas are called cross-disciplinary concepts and principles, common themes, unifying concepts, and cross-cutting concepts. These ideas serve two functions, one as frameworks for structuring the science curriculum, the other as a facet of science students are expected to come to understand. The assessment challenge is how to describe these ideas in ways in which they can be measured. An example of a cross-disciplinary idea, expressed as a principle, that is applicable to all the natural sciences is as follows: In a closed system energy is conserved. This principle relates three concepts, system, energy, and conservation. These ideas can be assessed as a principle or separately as one of the three concepts.

Evidence of knowing cross-disciplinary ideas includes the capacity to provide examples of cross-disciplinary ideas or the capacity to select cross-disciplinary principles or concepts from lists of principles and concepts some of which are cross-disciplinary and some of which are not. Evidence of understanding cross-disciplinary concepts is provided by the capacity to illustrate by example how the principles or concepts apply to situations in contexts related to different disciplines. Understanding is also indicated by the capacity to distinguish cross-disciplinary principles or concepts from principles and concepts which are not cross-disciplinary. Examples of tasks to evoke responses to be evaluated are the following: What are three cross-disciplinary ideas? Give an example of an idea that is cross-disciplinary and one that is not. Then explain why one idea is cross-disciplinary and the other is not.

Cross-References

► Assessment: An Overview

Cultural Change

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Keywords

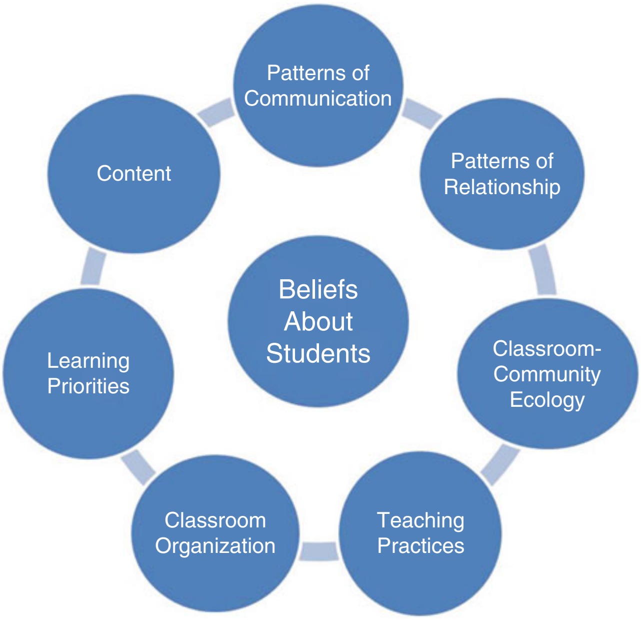
Knowledge; Learning; Science

Culturally Responsive Teaching of Science in Canadian Indigenous Settings

Although the science education literature has given attention to the importance of recognizing Indigenous knowledge systems in school science, less attention has been given to the teaching practices that should accompany this knowledge system inclusion and the processes that might accelerate these changes to curricula, including teaching practice. More recent developments in Canada's three most northern territories, the Yukon Territory, Northwest Territories (NWT), and Nunavut, draw attention to how political changes have potential for accelerating practices in education, and science education, specifically, that are responsive to Indigenous people's cultural knowledge systems and practices. In contrast to other provincial jurisdictions in Canada, treaties were historically never negotiated in these northern territories. Over the past three decades, the governments of both Canada and these northern territories have moved toward actualizing policy developments with its Indigenous peoples. These policy developments are commonly referred to as Self-Government Agreements (SGAs). SGAs are complex and wide ranging and include financial compensation, land, harvesting rights, heritage resources, and governance structures in areas like education and justice. The SGAs set out the powers of the government to govern itself, its citizens, and its land.

In the Yukon, the SGAs provide self-governing First Nations (SGFNs) with law-making authority in specific areas of First Nation jurisdiction, including education. For example, the Tr'ondëk Hwëch'in SGA provides for program delivery, design, and implementation of education programs for the Tr'ondëk Hwëch'in First Nation in the Dawson City area with the support and sanction of the Yukon Territorial Government (YTG). With the establishment of SGFNs, each FN with the required cooperation of YTG faces the challenge of reversing assimilation and regaining a sense of identity especially within the processes that influence the education of their children. Typical of most Aboriginal peoples, YFNs presently participate in a school system that has been drawn from the dominant culture, in their case southern Canadian school system models. Because of this, school processes and practices such as decision making in regard to the content of curricula, pedagogical practices and language of instruction have both intentionally and unintentionally denied the inclusion of those aspects of [YFN] culture that have value and are important to [YFN] children (Bishop and Glynn 1999). Consistent with the tenor of SGAs to work toward education practice more responsive to the Yukon's 14 First Nations, "culture-based education" has been more recently identified by YTG and its Education Act as one of the foundational principles for school development in the Yukon. YTG policy requires the activities of organizations in Yukon communities to create, preserve, promote, and enhance their culture, including arts, heritage, and language classrooms. This policy is based upon the principle that culture in all its expression provides a foundation for learning and growth and that YTG should support individuals, organizations, and communities to promote, preserve, and enhance their culture (YTG 2005). The educational experiences should be reflected not only in the management and operation processes of the school but also in the curricula and programs implemented and pedagogies used in classrooms. Although culture-based education may be rhetorically premised as the foundation of northern classrooms, what would classroom environments and teacher practices look like that are, indeed, reflective of YFN students' preferences? From the formal and informal learning of experiences of YFN community members, what would culturally responsive teaching look like, especially in science education?

Over the past decade (2002–2012), we, as researchers, have participated in and continue to participate in several research and development projects in our northern territories that focus on (1) determining Indigenous communities aspirations for education, especially science education; (2) identifying teaching practices, especially in science education, that are responsive to the learning interests, styles, and interests of students and the communities they represent; (3) developing with community members science education resources consistent with these interests, styles, and aspirations; (4) upon implementation, determining the influence of these pedagogies on student learning; and (5) based upon these findings, developing a description of what effective



Cultural Change, Fig. 1 Pedagogical framework for informing culturally responsive teaching of science

Cultural Change, Table 1 Attributes of culturally responsive teachers of science

Category	Description
*What are **my beliefs about students**?*	Students are regarded as culturally located individuals having capacity to learn, like any other, and contribute to my and the entire class' learning. Students expect me to have high expectations for them as learners and as members of a community
*What do I emphasize as the **content** to be learned?*	The formal science curriculum becomes the vehicle for the development of personal attributes deemed as important. Learning is not abstract. It focuses on and is located in local context and connected to students' lives. Science ideas are embedded with contexts, enriched through "working to end" type projects involving tangible end products. Literacy and numeracy development are emphasized as we are learning science. Developing fluency in these areas is a priority. What is learned does not compromise on students' cultural background. Instead it uses this to engage students and support their learning
*What **patterns of relationship** contribute to learning?*	The teachers' role is to cause learning. Establishing a classroom environment that promotes learning is the priority. Manifest in the relationships is a priority on caring. Caring manifests itself in actions – it supports, expects, challenges, affirms and is responsive to each individual and their situation. To do this, classroom routines are very important. Expectations and learning goals are clearly communicated and upheld. There is little compromise on established priorities, especially in regard to learning. Families are on board with these priorities and support these priorities. There is opportunity for students to contribute to decision making. Classroom allows for student voice in establishing consensus, but such that they never compromise on learning
*In what ways does this **classroom ecologically represent the community**?*	The classroom is physically represented through a variety of cultural representations and artifacts. Most importantly local language and community members and their protocols are welcomed and encouraged to be expressed. Learning is promoted through the participation of community members. Much learning occurs outside of the classroom because the community is seen as a contributing resource for fostering learning
*When I am teaching **how do I teach, and what are my practices for causing learning?***	In teaching practice, modeling and demonstrating are common. Visual images are commonly used to inform especially as a pre-reading exercise. Repetition and focus on mastery are emphasized. Time provision is made to gain mastery and think things through. Students show learning in a variety of ways, not just in written form and are given feedback to support next steps in learning. Collaboration and reciprocation in learning are important. The teacher and students must involve each other in a student's learning. It is vital that students are receiving individual attention and are given feedback and affirmation as they learn. Story telling and the use of narratives focusing on local context are frequent. Connections always made between prior learning and new learning across curriculum areas
*How can **classroom organization** say about how we learn and what is important in learning?*	Classroom routines are very important. Expectations are clearly communicated. There is opportunity for negotiation and renegotiation, especially because we are a community of individuals. Organization provides time, opportunity, and support for students to learn and show learning. Working for learning allows for assistance and feedback from peers

(*continued*)

Cultural Change, Table 1 (continued)

Category	Description
What should be the ***patterns of communication*** *when teaching and learning is occurring*	The communication patterns are dialogical rather than univocal, voluntary rather than involuntary. Listening is as important as talking. Sharing circles are a common practice to provide each student time and space to contribute, without interruption. As a teacher, I undertalk more commonly than I overtalk. When I talk with students individually or collectively, I physically situate myself at their level. Students communicate their learning through a variety of modes, not just in writing. The communication patterns are encouraged by a learning environment that focuses on learning as a collective activity
What are the ***learning priorities****?*	Focus is on the development of individuals who believe in themselves as culturally located individuals that are self-reliant, resilient, and contributors to their classroom and community. Although academic knowledge is important, the learning must be broader focusing on the development of life tools such as perseverance and self- sufficiency as well as interdependence and respect. Fundamental literacy and numeracy skills are regarded highly

teaching looks like within our northern schools (Lewthwaite and McMillan 2009; Lewthwaite and Renaud 2009; Lewthwaite and Wood 2009; Lewthwaite et al. 2010). Likely of most consequence from these studies is the understanding of what a culture-based teaching entails.

In Fig. 1 below, we illustrate the various factors that consistently surface as indicators of effective teaching practice in influencing positively student learning. At the center of the visualization are “beliefs about students.” In our experience with effective teachers in Indigenous settings, central to being a responsive teacher of science is a belief in the capability and cultural merits of each student. At the heart of many school systems’ thinking is a belief or, at least, an assumption that Western ways are superior and that Aboriginal culture and specifically students may bring deficits to classrooms, not assets. Such thinking suggests that not only are students’ background experience and knowledge of limited importance to promote learning, but so are their cultural foundations. Deficit thinking or theorizing, as it is called, is the notion that students, particularly low-income, minority students, fail in school because they and their families experience deficiencies such as limited intelligence or behaviors that obstruct learning. In contrast, those that effectively implement a culturally responsive pedagogy believe that students have a whole set of beliefs, skills, and understandings formed from their experience in their world and that their role as teachers is not to ignore or replace these understandings and skills, but to recognize and affirm them.

In Table 1 some more detailed insight into how teacher’s practice can be responsive to students’ cultural backgrounds. The table makes explicit the behaviors we commonly evidence in effective teachers. In brief, the actions of teachers are primarily focused on ensuring that their actions are *reflective* of students’ backgrounds.

At the heart of these effective practices is teachers of science accepting that they are the central players in fostering change, first in themselves by altering their beliefs about students and the cultures they represent and, then, working collaboratively toward an environment where practices reflect the culture in which students and their teaching practices assist students in their learning.

Cross-References

- ▶ Cultural Influences on Science Education
- ▶ Culture and Science Learning
- ▶ Learning of Science – A Socio-Cultural Perspective
- ▶ NOS: Cultural Perspectives

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Cultural Imperialism

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Keywords

Science Education in the Non-West

While *imperialism* refers to the establishment and maintenance of unequal relationships between countries or societies through conquest and political power, the term *cultural imperialism* is used to identify a form of ideological infiltration that enables some dominant states, organizations, or groups to impose their worldview, values, attitudes, behaviors, linguistic patterns, and lifestyle practices on others, sometimes by deliberate policy, sometimes by means of economic or technological superiority and influence. The term came to prominence in the 1970s through the work of Herbert Schiller (1976) who used it to describe the ways in which multinational companies and the mass media seduce, persuade, force, bully, or bribe social institutions and individuals to act in conformity with, or even to promote, the dominant ideology. Use of the term by scholars in history, philosophy, sociology, anthropology, education, and cultural studies is strongly influenced by the writing of post-structuralists such as Michel Foucault and Jacques Derrida, while in postcolonial discourse it is used to identify and define the cultural legacy of colonialism through forms of social action and organization, language use, and value judgements that contribute to the continuation of western hegemony long after independence.

Whatever the precise definition of cultural imperialism employed, it is apparent that education plays a key role in the establishment, maintenance, and legitimization of the views, beliefs, values, and practices of the dominant group. It does so through two interacting influences: *curriculum experiences*, what students encounter during lessons, and *informal learning experiences*, what is learned via the media (movies, TV and radio, newspapers), Internet sites, advertising, and visits to museums, zoos, aquaria, nature reserves, field centers, and the like. Curriculum experiences are of two kinds: those that are explicitly planned and those that are not. With regard to science education, there are many explicit messages about science, scientists, and scientific practice in textbooks, especially in passages that tell students what science is about and what scientists do when they are conducting investigations; there are explicit references to the nature of science and the history of science in curriculum materials designed for a science-technology-society (STS) approach, and there are references to cutting-edge science and the ethical issues it raises in curriculum materials addressing socioscientific issues (SSI). Teachers often draw explicit attention to features of science and scientific inquiry during laboratory activities and class discussions. Just as frequently, however, messages about the nature of science and scientific practice are not consciously planned by the teacher. Rather, they are implicit messages located in the language used, the kind of teaching and learning activities employed (especially in laboratory work), the examples of science and scientists utilized, the illustrative and biographical material in textbooks, and so on. Many students assume that whatever they do in science lessons, particularly during hands-on activities, mirrors what scientists themselves do as they conduct investigations. Over time, these experiences build into a particular set of messages about science, scientists, and the scientific enterprise. What is at issue here is a very powerful *hidden* or implicit curriculum that conveys messages just as powerful as those of the formal, planned curriculum.

Curriculum decisions (whether consciously or unconsciously made) necessarily reflect the perspectives of the decision-makers. Hence the selection of knowledge for the science curriculum does not reflect a common heritage but one rooted in the knowledge, assumptions, and values of those who have dominated society and educational discourse – in Western society, mostly white, male, and middle class. Further, because many of the individual messages about science are conveyed implicitly via teachers' day-to-day, short-term decisions about the conduct of lessons, the teacher's views constitute a major element of the overall story about science. In many cases, these views are located within a Western tradition, often a positivist tradition that regards science as having an all-purpose, straightforward, and reliable method of ascertaining the truth about the universe, with the certainty of scientific knowledge being located in objective observation, extensive data collection, and experimental verification. Moreover, scientists are seen as rational, logical, open-minded, and intellectually honest people who are required, by their commitment to the scientific enterprise, to adopt a disinterested, value-free, and analytical stance, in conformity with the norms of scientific practice postulated by Robert Merton (1973): universalism, communality, disinterestedness, and organized skepticism.

In making decisions about what to include or exclude from the curriculum, we not only define and limit what counts as science, we erect potential barriers that restrict access or make access to science and science education difficult. It is here that the notion of cultural imperialism can be helpful in focusing attention on the subtext of science education – in particular, on the exclusion of knowledge about the natural world accumulated outside of conventional Western science (variously described as traditional knowledge, Aboriginal knowledge, Indigenous knowledge, and traditional environmental or ecological knowledge); the neglect of ideas drawn from contemporary philosophy of science, history of science, and sociology of science; and the disregard of the perspectives of practicing scientists and the insight provided by commentators on the sometimes harsh realities of contemporary scientific practice – what John Ziman (2000) calls "post-academic science." The notion also raises awareness of the ways in which traditional knowledge and practices in many colonized countries were forcibly replaced by Western science and Western agricultural practices, often with untold damage to local ecosystems and destruction of the social fabric.

Cross-References

- ▶ Acculturation
- ▶ Poststructuralism and Science Education
- ▶ Science Education in the Non-West
- ▶ Science, Technology and Society (STS)

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Cultural Influences on Science Education

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Keywords

Categories; Culture; Cultural reproduction; Culture; Identity; Indigenous knowledge; Instruments; Nature of science; Otherness; Science Education in the Non-West

Acknowledgement of the role of cultural influences on science education is a relatively recent development, initiated in part by anthropological and sociological explorations of how specific contexts influence teaching and learning. Kenneth Tobin (2006) has written of science education experiencing a "cultural turn" as science education and discourse researchers begin to acknowledge and explore the influence of culture on science education, increasingly scrutinizing and critiquing universal notions of science practices and knowledge production. As a construct, culture owes its existence to the field of anthropology. Other fields, like education, with interests in the production of ideas, processes, and material social practices, have found the construct of culture to be useful for their purposes also.

What Is Culture? Models of Culture

At an abstract level, culture can be thought of as a theoretical category of social life that can be differentiated from other categories of similar stature such as politics, economy, and history (Sewell 1999). Typically, when we talk of culture, we are seeking to differentiate between different groups, identifying bounded entities of beliefs, practices, and ways of knowing as different cultures. Research that initially sought to explore cultural influences on science education was influenced by Clifford Geertz's (1973) notion of cultures as clearly bounded, consensual, and resistant to change. This model supported productive research in science education on student negotiation of "border crossings" between students' lifeworld culture and the culture of science leading Aikenhead to argue that treating science as a cultural enterprise constituted a radical shift in thinking for some science educators (see Aikenhead 1996).

But studies from history and sociology of science and from science education research have challenged this model of culture, leading researchers instead to endorse cultures as fields of material social practice and worlds of meaning that internally are contradictory, contested, subject to constant change, and weakly bounded (see Sewell 1999). The power of this model is that it allows researchers to acknowledge and value contradictions as well as coherences in data of human action, such as that collected from working with learners and teachers in classrooms, rather than try to explain away the contradictions that inevitably exist in all data sources.

Science Education, Cultural Reproduction

Historically, the goal of science education was twofold. First, all students would be assimilated into the culture of science through practice and assessment, a desirable end because of the superiority of science as a way of knowing and being. Second, through education, students would come to adopt and reproduce this superior form of knowing and being, including the norms, values and practices, and acceptance of what is real according to science (Aikenhead 1996). A cultural evaluation of these goals indicates that schooling has a role in ensuring that one vision of what constitutes scientific knowledge and practice is reproduced. However, challenges for this vision emerge in the differences between the everyday culture that students experience, in which they are experts, and the culture of science they are expected to reproduce throughout their educational experience in a school. A nuanced understanding of culture suggests, even more strongly, that the practice of assimilation exerts violence on students who come to science with different understandings. This construction of culture may help researchers to understand why so many students present negative perceptions of science or do not see science as part of their lifeworld and so do not choose to persist in science. Teachers may experience similar cultural disconnectedness from science; Carter (2008) uses the metaphor of science as a cultural story in order to allow beginning primary (elementary) teachers to identify a starting place for themselves in science.

Science as Culture and the Nature of Science

According to Sewell (1999), because cultures are contradictory, contested, and weakly bounded, the powerful (e.g., white, middle class, male in Western cultures) use power, not to establish uniformity, but to organize difference by identifying what is normal or accepted for a culture and marginalizing those that diverge from the norm. Such practices create a map of culture and difference, which tells people where they belong and what fits. However, because cultures are weakly bounded, loosely integrated, and contradictory, their borders are fuzzy and friable, and science education illustrates this issue very well.

What Is Science? In science education, one of the obvious questions that educators are often asked to explore is “What is the boundary of science”; in other words, “What is science and what is non-science?” While some science education researchers may present this boundary as objective and definite, implying that identifying science from nonscience is straightforward, a cultural perspective serves to help us identify the porousness of even this most strongly held belief about this boundary (see Pedynowski 2003). Additionally, cultural perspectives lead researchers and educators to accept that internally, science is heterogeneous and not homogenous as it is often presented in science education resources and in schools. One implication of accepting the porosity of this boundary and the heterogeneousness of the model of what constitutes science is accepting that there is an equally valid place in science for both the observational studies of geological sciences and the explanatory studies of particle physics. Studies within a specific science field also highlight that scientific work is nationally variable (see Fujimura 2000), not universally homogenous.

Traditionally, the development of scientific understanding has been presented as universal; immune to the culture, ethnicity, gender, race, sexual orientation, or religion of the knower; and dependent only on the restrictions of the natural world. However, cultural perspectives reject universal essentialist claims of scientific knowledge, recognizing that the practices, norms, and products of scientific inquiry vary across time and fields (disciplines) and encourage pluralist claims associated with the nature of science. Pluralist models of science education accept that all forms of knowledge exist in a cultural context, so the knowledge must be imbued with the values that are espoused by a culture. A willingness to accept the value-laden nature of knowledge construction is one of the first steps towards developing a richer understanding of a discipline, like science. These perspectives are illustrative of ongoing debates in science education between proponents of pluralist and universalist models of science education and the role of indigenous knowledge in science education (see McKinley 2005)

Beyond Concepts. The notion of culture as material social practices leads researchers to recognize the role of historical context in the development of these practices and associated meanings. For example, in my exploration of the history of understanding the relationship between boiling point and pressure, shows that the development of the thermometer (material practice) was just as important as the conceptual development of an understanding of air pressure and boiling point (social practice) (Milne 2013). Without a way to measure temperature, the conceptual questions could not even be framed. Cultural sensitivity of social practice also leads researchers to acknowledge their cultural stance with respect to the field they are seeking to explore. For example, researchers developing a survey instrument or identifying questions they wish to ask research participants in an interview will always explain in their writings how their understandings, positions, and biases with respect to the concept or construct they wanted to investigate informed and influenced the questions they asked the participants. Typically, this is the practice most ignored by researchers without a cultural perspective.

Belonging to a Culture and Otherness: Categorizing Identity

One other area where culture has influenced science education is in helping us to understand the interaction between individuals and culture in terms of how individuals construct themselves or are constructed; that is their identity. Individual and group identities are culturally and socially constructed around categories such as ethnicity, gender, race, sexual orientation, religion, and occupation, and individual people are categorized in various ways. Identity can be thought of as an objective sense of oneself, which individuals present to others for confirmation. Categories, such as white, Asian, woman, and brainy, can also be inscribed on people as an identifier of belonging to a particular group whether or not they wish to be so categorized. An individual's identity is strongly connected to the cultural production (learning) she has experienced which can be disturbed if someone experiences a culture very different to that with which they are familiar and which they can experience as a form of "culture shock" (see Michie 2011). With greater cultural awareness, researchers and educators are more open to exploring how cultural categories, such as race and gender, are embedded in presentations of scientific knowledge. For example, Bazzul and Sykes (2011) examined heteronormative representations of gender in a biology textbook used with high school students raising the question of why such textbooks represent the constructs of sex and gender as identical and exclusively about men and women to such a vulnerable population.

Generalizing and Otherness. Cultural influences also induce researchers and educators to cast a critical eye on attempts to generalize behavior to a small set of principles. While we can celebrate Galileo's use of idealization to propose the existence of gravity or Piaget's attempt to find universal structures in learning and behavior, cultural perspectives support us to recognize that with this focus on sameness, we lose sight of difference. In many cases, difference becomes identified as otherness. A cultural perspective may prompt researchers to examine critically a catchphrase like, "Science for All," asking, "Whose science? Who is left out?"

Summing Up

This short entry provides just an inkling of how culture influences science education. But hopefully it has communicated how any exploration of cultural influences from coherence and contradictions to identity and instruments offers the potential for a richer, more nuanced understanding of some of the elements that could serve to develop a more humane and inclusive science education. An understanding of cultural influences reinforces the notion that we have a responsibility to look with a critical eye, locally and globally, at how science education and science construct and use knowledge. We must examine not only who is included and marginalized through our stances, but how science education can better support the science learning of all children and youth. Finally, cultural influences support educators to answer one of the most important questions in science education, How does education support learners to see a role for science in their individual identities?

Cross-References

▶ Borders/Border Crossing
▶ Cultural Imperialism
▶ Cultural Values and Science Education

- ▶ Culturally-Relevant Pedagogy
- ▶ Culture and Science Learning
- ▶ Gender
- ▶ Identity
- ▶ Indigenous Knowledge
- ▶ NOS: Cultural Perspectives
- ▶ Retention of Minorities in Science
- ▶ Science Education in the Non-West
- ▶ Socio-Cultural Perspectives and Characteristics
- ▶ Socio-Cultural Perspectives on Learning Science
- ▶ Values and Indigenous Knowledge
- ▶ Values and Western Science Knowledge

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Cultural Values and Science Education

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Cultural Values and Science Education

Culture is the cumulated experiences of a people group which shape their behavior and overall worldview. Cultural values are attributes that a people group considers to be critical to its survival. Science is a systematic endeavor which attempts to describe, explain, predict, and control nature. Science education is the field of study expressly concerned with two important goals: (1) the development of potential scientific human power and (2) the development of a scientifically (and technologically) literate society. In a world dominated by science and technology, the development of a scientifically literate citizenry is imperative. But in the pursuit of scientific literacy, it is worth noting that certain cultural values differ remarkably from those of science. Also, not all cultural values are associated with science, i.e., there are cultural values which strictly speaking are outside the realm of science. At times, science education must make connections between science and broader cultural values. A contest of values between science and culture serves neither the interests of the students, their communities, nor those of the scientific community.

Cross-References

- ▶ Culture and Science Learning
- ▶ Learning of Science – A Socio-Cultural Perspective

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Culturally-Relevant Pedagogy

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Keywords

Border crossing; Discourse; Funds of knowledge; Hybridity; Third space

A hallmark of science education near the end of the twentieth century was the recognition of the importance of culturally relevant pedagogy (CRP), a term first coined in 1995 by Gloria Ladson-Billings. Since the initial introduction of this concept, a deeper understanding of CRP has evolved through a variety of discourses, particularly in relation to its application in science education. Each of these discourses in some way reflects aspects of Ladson-Billings' (1995) criteria for culturally relevant pedagogy: (1) high expectations for all students to experience success, (2) the development or maintenance of cultural competence, and (3) the construction of a critical consciousness or critical literacy which fosters an analysis of the hidden forces of power which shape our logic, anesthetize our ethics, and even define what we call a problem. In today's twenty-first-century science classrooms, science educators must continue to employ sociocultural consciousness, which draws inspiration from and builds curricula around ways of seeing beyond our differences. Rather than melting difference to make us all the same, we must celebrate the backgrounds of students and make them equally valid in order to provide all learners with the opportunity to experience scientific success.

CRP is especially important considering the increasing diversity due to the mobility of today's world population. Students and families are much more transnational now than ever before due to increased air transportation and Internet. As Carter (2012) points out, our "everyday consciousness is now one of a global imagery, making us feel connected to far-flung places and events" (p. 899). As the world's population mobility continues to escalate, it is likely these changes will endure and increase the diversity in student populations. Thus, it is important to recognize that various conceptualizations or discourses surrounding CRP have, in recent years, been embedded in a larger macro-discourse, the complex sociopolitical-economic context of globalization. An alternative to this is a discourse of "glocalization," whereby a dialectical relationship between local and global practices creates opportunities for a more pluralistic science education.

CRP is an idea which merges conceptions of culture, relevance, and pedagogy in unique ways. From a sociocultural perspective, culture can be viewed as very fluid, lacking coherent boundaries, and ever changing. It is enacted or produced through agency, in which actors, both individually and collectively, consciously appropriate structures in ways that are goal oriented and intentioned. Culture is also created passively in ways that may be aligned to specific goals such that "an actor is aware of culture being created over which she/he does not have complete control" (Tobin 2012, p. 5). In this sense, culture can be depicted as a continuous dialectical relationship between agency and passivity. In contrast to mythical, romantic, and stable myths, pedagogy that is culturally relevant constantly asks the question of whose science and for what purposes are students learning. Pedagogy, often described as the art of teaching, involves the skills, mindsets, beliefs, and knowledge an individual constructs in order to teach subjects such as science. Taken together, CRP emerges as a concept historically described and sometimes used interchangeably with "culturally congruent" and "culturally responsive teaching." It has been compared to a bridge connecting home and school cultures and described as teaching that aims to create democratic and multicultural classrooms that empower students. However, CRP takes on new meaning in light of sociocultural perspectives on science teaching and learning.

In the context of science education, CRP can be viewed through the lens of various discourses, which develop our ability to see from multiple frames of reference. The complexity, integration, and overlap of these various discourses can help us discern further insight into some of the limitations of earlier conceptions of the term. Furthermore, these discourses are beneficial because they represent the ways people have discussed CRP and show how a deeper understanding of how it has evolved in science education.

One of the most often discussed discourses promoting CRP in science education is the notion of "border crossing." This discourse suggests that when students' life experiences differ from the culture of school science, they may feel alienated by science if no attempt is made by the teacher to understand and incorporate their cultures into the science classroom. Non-mainstream students may feel this even more strongly if the examples and topics presented in school are irrelevant to their lived experiences. This discourse further emphasizes the need for educators to use culturally relevant methods and topics to present material in ways that build on students' prior knowledges and experiences, making connections between the known and the unknown. Historically, the concept of border crossing was viewed as unidirectional (i.e., students crossing into school or western science). More recently, Aikenhead (2006) has emphasized the need for science education researchers to view border crossing as occurring in two directions: both into and out of school science. He suggests that Aboriginal peoples, for example, have certain indigenous knowledges that can and should be central to science learning. The discourse of border crossing argues that it is important to change the structures of schools to acknowledge the culture of students.

Another common discourse used in discussing and fostering CRP centers around the idea of community funds of knowledge. Funds of knowledge are the experiences, values, identities, and feelings that comprise a child's life. From the perspective of this discourse, student learning and interest can be maximized when educators build on the funds of knowledge of the learner and his or her community. By building on prior knowledge, language, traditions, ways of knowing, and place-based narratives, important connections can be made between students' everyday lives and science. For example, in many rural areas with a strong sense of community, intergenerational knowledge is passed down and this knowledge includes nutritional choices and values. Students could develop nutritional literacies, by investigating dietary lifestyles of members of the community. In this way, we can build curricula and our ways of seeing by drawing inspiration from individual and community funds of knowledge.

CRP can also be encouraged through a discourse centered around creating a practicing culture of science learners. A practicing culture of science learners is a community of people who are learning about science as they do science in ways that mirror the practice of scientists. A community garden, for example, is a place where students can learn about plant biology by producing science as their garden grows. The garden is a context in which students can come together with local people and share in making decisions about their everyday lives and natural environments. Local people are at the heart of a practicing culture of science learners. Students can practice science outside the classroom and learn by doing, even when new information and experiences may be at odds with students' existing understandings. A community garden grown in an urban setting might feel very foreign to students initially, but by growing some of their favorite foods and sharing with their families and friends, it could become familiar and foster a genuine interest in science.

CRP discourse has also taken a critical stance. It has challenged science educators to think critically about how knowledge can be used to educate students and make social changes rather than fuel social reproduction. This is an idea similar to what Ladson-Billings (1995) described as the critical consciousness tenant of CRP which encourages students to learn to critique and interrupt current and historical social inequities. Critical discussions can encourage and empower students to think individually and not just take for granted mainstream science ideology. Consider, for example, an ecology class in an urban setting where students might read about factories polluting the air of the neighboring countryside where their food is grown. Students could conduct research to become informed about this socio-scientific issue, use this information to make decisions about the health of their community, and take appropriate actions. The challenge is to apply examples in textbooks and other resources to something students might have experienced and give them the tools to make a difference in their lives and those of community members.

More recent discourses surrounding CRP are centered on notions of third space and hybridity. Third space involves the intersections between students' home-community culture and school culture. It is the arbitrary area where culturally relevant teaching connects students' life worlds. Third space is not just accomplished by building bridges between differing cultures, but by using what has been learned about the past and present to facilitate change. For example, Paris (2012) notes that children of migrant farm workers can learn about their culture, where their families came from, where they are now, and the possibilities for their futures. In this way, students join their homes and communities with schools in meaningful ways without devaluing their history and cultures.

Whereas third space is about locating the knowledge in an area, the concept of hybridity is about creating a new type of knowledge. This new knowledge is made by blending students' home culture with the culture of school science and results in a hybridized culture that emphasizes heterogeneity. The additional twist of hybridity, compared to third space, is that students must also come to know and understand the culture of the teacher. In this way, the classroom and participants are constantly embracing multiculturalism. To assist in the cultural blending process, culturally relevant examples are especially important. For example, traditional ecological knowledge (TEK) can be incorporated into science classrooms to facilitate hybridity for all learners. Both teachers and students would simultaneously expand their knowledge on various cultural systems and ecologies.

Moving beyond CRP is the next logical step in thinking about the kind of science education that will be meaningful to the twenty-first-century youth. Science educators are making a point of including relevant material in their classes, but the question "Relevant to what?" continues to be raised. Relevancy as curriculum-centered science and relevancy as community-based science are two concepts proposed as a next step. Curriculum-centered science involves input from various local educational and community sources in developing applicable materials and approaches to teaching science. In this case, the curriculum would be built from the bottom-up using local educational and community sources, instead of top-down from state or national standards. Community-based science changes the curriculum and connects it to the community where students live. It involves meeting students' families, learning about their home life, investigating issues within the community, and developing what is taught from what has been observed and suggested from community members.

Questions have been raised about the implications of CRP for the twenty-first-century learners. Is emphasizing high expectations, cultural competence, and critical consciousness enough to promote CRP and establish sociocultural consciousness and caring? While it is necessary for students to experience a diversity of curriculum materials and pedagogies reflecting a range of ideologies, educators must be cognizant to transcend "tip of the iceberg" conceptions of culture. Many times, curriculum materials and pedagogies are designated as culturally relevant because they include dress, folk dancing, cooking, or music from a variety of cultures. However, while these surface conceptions of culture may promote cultural awareness, they might actually lead to more ridicule and stereotyping of certain students. Besides being relevant and responsive, curriculum and pedagogies should be culturally sustaining. Culturally sustaining pedagogies, such as encouraging the use of student's first language as they communicate amongst themselves during a lab session, will perpetuate and support cultural pluralism. The discourses and educational frameworks that shape our understandings of CRP should be constantly challenged, amended, and extended by "testing out" their theoretical soundness through diverse research methodologies. As demographics change, science education must also evolve to include culturally relevant pedagogies and curriculum that will promote and enhance science achievement for the twenty-first-century learners.

Cross-References

- ▶ Borders/Border Crossing
- ▶ Cultural Change
- ▶ Culture and Science Learning
- ▶ Ecojustice Pedagogy
- ▶ Worldview

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Culture and Science Learning

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Keywords

Culture

This entry seeks to summarize our understanding of the processes of science learning that occur within and at the intersection of diverse worldviews and knowledge systems, drawing upon experiences of various indigenous societies. The curricula, teaching methodologies, and assessment strategies associated with mainstream schooling are based on a worldview that does not adequately recognize or appreciate indigenous notions of an interdependent universe and the importance of place in their societies (Kawagley 2006). Many indigenous as well as nonindigenous people have begun to recognize the limitations of a monocultural education system, and new approaches have begun to emerge that are contributing to our understanding of the relationship between indigenous ways of knowing and those associated with western society and formal education. Our challenge is to devise a system of education for all people that respects the epistemological and pedagogical foundations provided by both indigenous and western cultural traditions.

While western science and education tend to emphasize compartmentalized knowledge which is often decontextualized and taught in the detached setting of a classroom or laboratory, indigenous people have traditionally acquired their knowledge through direct experience in the natural world. For them, the particulars come to be understood in relation to the whole, and the "laws" are continually tested in the context of everyday survival (Cajete 2000). Western thought also differs from indigenous thought in its notion of competency. In western terms, competency is often assessed based on predetermined ideas of what a person should know, which is then measured indirectly through various forms of "objective" tests. Such an approach does not address whether the person is actually capable of putting that knowledge into practice. In the traditional native sense, competency has an unequivocal relationship to survival or extinction – if you fail as a caribou hunter, your whole family may be in jeopardy. You either have it, or you don't, and it is tested in a real-world context.

Indigenous people do a form of "science" when they are involved in the annual cycle of subsistence activities. For a student imbued with an indigenous, experientially grounded, holistic worldview, typical approaches to schooling can present an impediment to learning, to the extent that they focus on compartmentalized knowledge with little regard for how academic subjects relate to one another or to the surrounding universe.

To bring significance to learning in indigenous settings, the explanations of natural phenomena are best understood by students if they are cast first in indigenous terms to which they can relate and then explained in western terms (Aikenhead 2001). For example, when choosing an eddy along the river for placing a fishing net, it can be explained initially in the indigenous way of understanding, pointing out the currents, the movement of debris and sediment in the water, the likely path of the fish, the condition of the river bank, upstream conditions affecting water levels, the impact of passing boats, etc. Once the students understand the significance of the knowledge being presented, it can then be explained in western terms, such as flow, velocity, resistance, turbidity, sonar readings, tide tables, etc., to illustrate how the modern explanation adds to the traditional understanding (and vice versa). All learning can start with what the student and community already know and have experienced in everyday life. The indigenous student (as with most students) will then become more motivated to learn when the subject matter is based on something useful and suitable to the livelihood of the community and is presented in a way that reflects a familiar worldview (Kawagley 2006).

There is a growing awareness of the depth and breadth of knowledge that is extant in many indigenous societies and its potential value in addressing issues of contemporary significance, including the adaptive processes associated with learning and knowledge construction (Battiste 2002). The new sciences of chaos and complexity and the study of nonlinear dynamic systems have helped western scientists to also recognize order in phenomena that were previously considered chaotic and random. These patterns reveal new sets of relationships which point to the essential balances and diversity that help nature to thrive. Indigenous people have long recognized these interdependencies and have sought to maintain harmony with all of life. With fractal geometry, holographic images, and the sciences of chaos and complexity, the western thought-world has begun to focus more attention on relationships, as its proponents recognize the interconnectedness in all elements of the world around us. Thus there is a growing appreciation of the complementarity that exists between what were previously considered two disparate and irreconcilable systems of thought (Kawagley and Barnhardt 1999).

The incongruities between western institutional structures and practices and indigenous cultural forms are not easy to reconcile. The complexities that come into play when two fundamentally different worldviews converge present a formidable challenge. The specialization, standardization, compartmentalization, and systematization that are inherent features of most western bureaucratic forms of organization are often in direct conflict with social structures and practices in indigenous societies, which tend toward collective decision-making, extended kinship structures, ascribed authority vested in elders, flexible notions of time, and traditions of informality in everyday affairs (Barnhardt and Kawagley 2008). It is little wonder then that formal education structures, which often epitomize western bureaucratic forms, have been found wanting in addressing the educational needs of traditional societies.

When engaging in the kind of comparative analysis of different worldviews outlined above, any generalizations should be recognized as indicative and not definitive, since indigenous knowledge systems are diverse themselves and are constantly adapting and changing in response to new conditions. The qualities identified for both indigenous and western knowledge systems represent tendencies rather than fixed traits and thus must be used cautiously to avoid overgeneralization (Gutierrez and Rogoff 2003). At the same time, it is the diversity and dynamics of indigenous societies that enrich our efforts as we seek avenues to integrate indigenous knowledge systems in a complementary way with the system of education we call schooling.

Cross-References

▶ Acculturation
▶ Cultural Influences on Science Education
▶ Science Education in the Non-West

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Curriculum

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Keywords

Aims; Assessment; Attained; Intended; Policy; Laboratory; Subjects; Taught; Teaching; Theoretic

The word “curriculum” referred originally to the track around which Greek and Roman chariots raced, but its first educational use was at the University of Glasgow in 1824 to refer to the course of study followed by undergraduates. While the word has been defined in a variety of ways, it is almost always associated with formal education (i.e., schools, colleges, and universities) and refers to the content of a student’s educational program. The term is used throughout the English-speaking world, but, despite its Latin origin, it is not commonly found as a cognate in other European languages.

The curriculum, both the overall curriculum and the curriculum of any specific subject, such as the science curriculum, expresses the purposes, goals, or *aims* for education. While informal learning (such as that taking place in play) can be random and aimless, formal education in schools always has aims or purposes that permeate instruction, and these are usually stated in curriculum documents. In addition, the curriculum also has subject-matter *content*. An overall curriculum can consist of any number of subject fields (or they can be integrated), and within each one there are usually topics or themes to be taught at each year or group of years. A curriculum may also contain statements about the processes of teaching and learning, and these are often a logical consequence of the curriculum aims. For example, a curriculum could have, as one of its aims, that students will develop the skills of investigation. Such an aim would imply that the teaching of the subject-matter topics would include providing opportunities for pupils to undertake investigations into those topics. Finally, a curriculum may contain explicit or implicit statements about the assessment that should be carried out in relation to both the aims and content.

But a curriculum is much more than a static statement or document. The curriculum that an individual student actually experiences is the result of decisions made at various levels, some far removed from the classroom. In many jurisdictions, some of these decisions are taken at the government level, where Ministries or Departments of Education set out curriculum policies relating to schools under their control. These may outline, for example, the subjects that students should study at each level of schooling; they may include more detailed lists of topics to be taught at each year or grade; and they may also specify textbooks or published courses that teachers must follow. All such policies exemplify what is called the *intended* curriculum. Regional or local school authorities below those of the national government, examination boards, and even schools themselves may also issue curriculum or syllabus specifications. These are all elements of the intended curriculum, and most teachers develop their instructional activities on the basis of some externally mandated curriculum policies of this nature.

At the classroom level, each teacher delivers what has been described as the *implemented* or *taught* curriculum. This curriculum is based in part on the intended curriculum (or at least on a teacher's understanding or perception of it), in part on resources available and used by the teacher (such as textbooks and other curriculum resources), and in part on the teacher's own philosophy, ideas, and perceptions of the students' needs. As a result of this combination of inputs, the taught curriculum can often differ in significant ways from the intended curriculum, and these differences have been the subject of much empirical research over the years.

Finally, at the level of each individual student, there is what is known as the *learned* or *attained* curriculum. This is obviously related to the taught curriculum but also differs from it. While the taught curriculum is usually delivered to a whole class of students, learning takes place within the mind of each student and is the result not only of the instruction but also of what was known before, of each student's interests and abilities, and of the circumstances of the classroom situation. Sometimes little of what was intended or taught is actually learned. Sometimes, additional, unintended learning takes place (what Dewey called "collateral learnings"). These additional learnings have also been called the "hidden curriculum" because they are not part of the intended curriculum or even an explicit aspect of the taught curriculum.

The curriculum aims, content, teaching processes, and assessment can be thought about and observed at the levels of the intention, teaching, and learning. But the intentions in a given curriculum may not be fully realized in the taught curriculum, and those of the taught curriculum may not be attained in the learned curriculum. These differences have given rise to much curriculum research but also point to one of the central realities of curriculum: while much can be written as policy, as textbook, as advice to teachers, and so on, all of these are *theoretically* based. And ultimately, as Joseph Schwab pointed out, curriculum is *practical* in that it is set in the situations of particular classrooms and the needs of specific pupils. This tension between theoretic and practical lies at the heart of much curriculum discourse.

Cross-References

- ▶ Curriculum Evaluation
- ▶ Didaktik
- ▶ History of Science in the Curriculum
- ▶ Transposition Didactique

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Curriculum and Values

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Keywords

Curriculum; Values

Links Between Curriculum and Values

As pointed out by Graham Orpwood in this encyclopedia, “The curriculum…expresses the purposes, goals and aims for education” (see curriculum; emphasis in original). Inherent in this statement is some notion of what is judged by experts to be important in education. In developing any curriculum, the belief system underpinning the political, cultural, and economic contexts of the system will be represented. However, such representations are very often implicit and often not even recognized by those developing the curriculum.

Curriculum also consists of subject matter content (Orpwood). This content, science in this case, is also linked to values in three ways (Allchin 1998): values that guide scientific research itself, values that enter science through its practitioners, and values that emerge from science (both product and practice).

Values

There are many definitions that can be used for values (Halman 2010). This may be due to the nature of values as mental constructs; consequently the values people hold can never be observed, but only inferred. Halstead (1996, p. 5) captures the essence of these many definitions in characterizing values as “the principles . . . or life stances which act as general guides . . . in decision-making or the evaluation of beliefs or actions and which are closely connected to personal integrity and identity.” He highlights the more enduring and basic nature of values as compared to beliefs and attitudes. Values also can underpin a disposition or a person’s tendency to act.

Values of Science

It has been quite a common notion amongst some scientists, science educators, and the general community that science is “value-free.” Such ideas have often been perpetuated in the study of science and in science communication, particularly through the focus of science being objective. But objectivity is not really possible as science is a human construction – a way of explaining our natural world.

Science is a way of thinking (and acting) as it is a knowledge-seeking enterprise. It is therefore important to establish the values that underpin this way of thinking (and acting or disposition to acting).

Values in science can be seen as epistemic or sociological in nature. Epistemic values distinguish knowledge that is intrinsically worth knowing and includes the knowledge currently accepted by the scientific community in the form of theoretical explanations for the real world. These values emerge from science as both a product and a practice (see Allchin 1998).

Sociological values include consideration of both external and internal sociological perspectives. External sociological perspectives will include those values that guide scientific research, while internal sociological perspectives include values that enter science through its practitioners. External sociological values of science include the way in which scientists are viewed as experts or possessing some authority within their field of expertise, whether their research should be funded based on decisions about its benefits to society and how scientists communicate their research findings to the public. Internal sociological values of science include the personal values that scientists hold as scientists and consequently as members of the scientific community as well as the personal values a scientist has as a member of society.

Values that underpin science often include curiosity and skepticism, rational thinking, empiricism, parsimony (which could include reliability), robustness, fruitfulness, community practice (as in the community of scientists), interdependence (with other scientists and their research), accuracy, reduction of bias (rather than complete objectivity), open-mindedness, and creativity (which might encompass imagination, innovation, intuition, and informed guesses).

Many of these values may be common to other disciplines such as mathematics and history, but the way in which such values play out in science, both individually and as a collective of values, is very different. For example, while rational thinking is an important value in both science and mathematics, the way it plays out in each of these disciplines can be very different. Rational thinking includes the notions of argument, reasoning, logical analysis, and explanations. It concerns theory, and hypothetical and abstract situations, and thereby promotes universalist thinking. The value can be demonstrated by developing skills in argument and logical reasoning. In mathematics it involves understanding the role of proof and proving, while in science is more about validating the development of knowledge, engaging in discussion and debate, seeking explanations for experimental data, and contrasting alternative hypotheses in terms of available data.

For the individual, then, the interpretation of seemingly the same value has different representations or manifestations in different disciplines, and, while the similarities enable the individual to make sense of the different disciplines, the differences create tensions and can limit their ability to make sense of these disciplines.

Other values such as empiricism (the view that experience, especially of the senses, is the only form of knowledge) are quite unique to science. Science as a way of thinking and acting (or a disposition to act) then is underpinned by the set of values highlighted above that are quite diverse in their nature as they cross epistemic and sociological perspectives.

Values in Science Education

Science as a discipline can be viewed as a particular way of thinking and acting. In science education, experiences of such thinking and acting need to be provided if students are to develop some expertise in the discipline of science. The thinking and acting required in science and science education means that people need to be curious enough to explore their natural environment and try to explain it. In this process of curiosity and/or inquiry, a person needs to engage in some sort of observations (through direct or indirect use of the senses) for some purpose. For example, if you want to know whether you will find a particular bug in a particular place, it is not enough to just look at a bug, but rather you need to look at where the bug is or what it looks like, what color is it, does it have wings, does it have a hard shell, and so on. There is a purpose to your observations, purposes that in essence generate data (which is often uniquely empirical in nature as these are from observations). You then need to look at these data and decide if there are any patterns, ways you can group the data or classify the data (rational thinking). In considering what is the same or different about these data means that you are beginning to place your own meaning (or inferences) on these data. Some of these inferences will be more meaningful than others according to the grouping or patterns. So at this point there are judgments being made about which data are more relevant to the purpose of collecting the data. Those data with the most meaning will contribute to evidence you will use to create an explanation or a model, while data that are less helpful will often be ignored. From here more investigation is required if you are to decide how useful is the explanation or model (often framed as how robust is it) in explaining what I have seen and in enabling me to make predictions about other similar situations/scenarios. If it is useful (or robust) it will explain or fit most situations (not all) – so these explanations or models are useful (plausible, fruitful, and testable). It is also often the case that the simplest explanation/model is the one that suits the most situations (parsimony). If these explanations or models can be combined in ways that build up more complex structures to explore more complex systems, then their use becomes important in terms of understanding how systems will respond if changes are made to them. A fundamental aspect of all of this process is the need to communicate your explanations/models/systems to others to see what they think and to clarify your own thinking (community, collaboration, interdependence, consensus).

The process outlined above is one way that highlights many of the values that underpin science as a way of thinking and acting, many of which are indicated in the brackets in the previous paragraph. The experiences students have in science education must also be inclusive of these values.

Values and the Curriculum

It is rare for curriculum documents to explicitly articulate either the general values underpinning the curriculum or the specific discipline-based values that are included. Nor do curriculum documents highlight the evolving nature of how such values may be interpreted or manifested over time. For example, the recent rapid growth of systems science and interdisciplinary science fields such as biomolecular chemistry and bioinformatics have meant that the thinking and acting needed in these instances are still consistent with the underpinning values but can be represented or manifested in very different ways. Similarly, continued technological developments mean the notion of empiricism has gone far beyond simple observation.

In expressing the purposes, goals, and aims for education, curriculum documents need to also express the values that underpin these purposes, goals, and aims, both in a general sense and in a discipline-specific sense. For science education to provide more authentic experiences of science, teachers and students alike need to be aware of the values that underpin the experiences they engage in and how these contribute to the development of the values that underpin science as a way of thinking and acting.

Cross-References

- ▶ Authentic Science
- ▶ Bildung
- ▶ Curriculum
- ▶ Curriculum Emphasis
- ▶ Didaktik
- ▶ Empiricism
- ▶ History of Science
- ▶ Hypothetico-Deductive Method
- ▶ Process Science
- ▶ Transposition Didactique
- ▶ Values and Learning Science

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Curriculum Development

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Science curriculum development can involve changes in what is taught, to whom (target audiences), and how (ways of teaching and learning). This entry is concerned with the following questions: *Why* change the science curriculum? *What* should be changed? *How and by whom* is the change process initiated and sustained? The entry discusses various models for initiating and sustaining change.

Why and What to Change? Goals and Driving Factors

Throughout the last 60 years the goals and objectives for science teaching and learning have undergone changes many times, often leading to reforms in the way the science curriculum was developed, taught, and learned. Five key factors influence a change in curriculum goals: the learners (target population), the teachers, the science content, the context of learning and teaching both in and out of school, and the assessment of students' achievement and progress.

The Learners

A long tradition of research on learning and teaching science suggests that learners are

> Goal-directed agents who actively seek information. They come to formal education with a range of prior knowledge, skills, beliefs. In addition, they are directed by their concepts, interest, motivation, and attitudes that significantly influence what they notice about the environment and how they organize and interpret it. This, in turn, affects their abilities to remember, reason, solve problems, and acquire new knowledge. (National Research Council 1999, p. 10)

Studies also indicate that affective (interest, motivation, and attitudes), meta-cognitive, and sociocultural aspects play an important role in the learning-teaching process (Linn et al. 1996). There is agreement among many science educators that the range (or repertoire) of the learners' ideas and ways of making sense of the world should be a key factor in setting curricular goals and in developing teaching strategies and learning materials. Learners' prior ideas and those developed in the process of learning have been researched extensively, indicating that they often depart significantly from the normative ones. The abstract nature of scientific concepts and principles and the need to understand phenomena and interactions that are not directly observable, in particular large or very small spatial and temporal scales, are examples of challenges facing science learners. Some learners' ideas are resistant to change while others may stem, for example, from missing knowledge or confusing use of terms and can be easily remedied. Departmentalization of using science differently in different contexts has been documented extensively (e.g., "school science" vs. out-of-school science ideas or the use of a certain concept differently in different disciplines). Therefore, characterizing the sources of learners' ideas and how they are used has a significant impact on the design of curriculum.

In the process of science learning, learners, either as individuals or as a group studying together, may grapple with a repertoire of ideas that are not necessarily consistent with each other. Science educators hold different opinions regarding the repertoire of learners' ideas. Some regard them as barriers to the process of learning and design strategies to eliminate them, while others regard the repertoire as an essential and useful resource enabling learners to build on their experience and intuitions. Therefore, the curricular goals, the teaching strategies, and the assessments differ in these approaches.

It should be noted that some aspects of learning and teaching science described above hold for all science learners, yet changes in the target population of science learners over the last decade have had a significant impact on science curriculum development. For example, in the USA in the 1960s, the goals were strongly based on the view that science learning should serve students who plan to embark in the future on a career in the sciences, engineering, or medicine. The American Association for the Advancement of Science in 1962 summarized the goals of these curricular initiatives as follows:

- Science education should present learners with a real picture of science, including theories and models.
- Science education should present an authentic picture of scientists and their method of research.
- Science education should present the nature of science (NOS).
- Science education should be structured and developed using the discipline approach (key concepts in each of the subjects).

To attain these goals, a series of science curricula, such as PSSC in physics, BSCS in biology and CHEMStudy in chemistry in the USA, and the Nuffield courses in the UK, were developed. The development teams were led by scientists. All teams included teachers, but the teachers played different roles in the development process. For instance, the development teams in the Nuffield courses consisted mainly of leading teachers. About 20 years later, in the 1980s, there was a shift in many countries toward addressing the needs and abilities of all citizens. For example, an NSF sponsored project, *Project Synthesis*, which analyzed science curricula in previous years, led to a call to change the scope and goals for science teaching and learning, advocating that science education should:

- Include major concerns regarding science as a means of resolving current societal problem.
- Provide a means to attend to the personal needs of students.
- Provide greater awareness of potential careers in science, technology, and related fields.

These goals led, for example, to curriculum projects focusing on science, society, and technology (STS) around the world. Attempts have been made to make science more relevant to learners and adjusted to their backgrounds (e.g., the Chemistry in Context and the Chemcom curricula), attending to characteristics such as equity; gender; students' attitudes, interest, and motivation; conceptual understanding; creativity and curiosity; and knowledge integration.

The Teachers

One of the key factors regarding curriculum change is the teachers. In general, teachers are reluctant to accept radical changes and often do not implement them in accordance with the rationale for the change suggested by the curriculum developers. Such changes may not be aligned with teachers' existing views and practices and may require new knowledge, perhaps content knowledge (CK), or its related pedagogical content knowledge (PCK), or curricular knowledge. Important factors influencing teachers' response to change include personal characteristics, cultural norms (e.g., the role of questioning), the professional status of the teacher, the teacher's understanding of the proposed change and its rationale, and systemic approaches to students' future career opportunities.

The Scientific Content and Organization

The scientific content and the skills or scientific practices to be learned constitute the major fabric of the curriculum. Criteria for choosing scientific core ideas may relate to the importance of concepts within and across disciplines; the provision of key tools for understanding, investigating, and problem-solving; enhancing interest; the relevance to life experiences and the connection to personal and societal concerns; and being teachable and learnable over multiple grades at increasing levels of depth and sophistication (e.g., "learning progressions"). Changes in conceptions about how topics should be organized have also influenced curricular change. For example, "context-based science" (e.g., in the PLON curriculum in the Netherlands and the Salters' projects in the UK) and "knowledge for use" approaches depart significantly from the traditional "structure of the discipline" approach often used for science curriculum development.

Aligning school science with contemporary scientific knowledge is an important consideration in areas that change at a very rapid pace such as molecular biology or nano-science, as well as topics that are interdisciplinary in nature such as brain science and medicine. Changes of this kind in the fields of science and technology are the driving force behind many innovations in school STEM curricula.

Another central issue is the methodologies used for enhancing the acquisition of skills in science curricula. There is a consensus that skills should be developed in the context of content and that in order to develop a generalizable skill (transfer), it must be studied explicitly and practiced in different topics. However, different ways of doing this lead to different curriculum structures.

The Context of Learning and Teaching: The Learning Environment

Learning and teaching science takes place in-school and out-of-school learning environments. Each setting has important benefits as well as limitations. Changes in the learning environment have been shown to influence students' motivation and learning. These changes involve instructional approaches (e.g., inquiry and project-based learning, small group cooperative learning, debates on issues, use of games, and digital simulations) as well as the physical settings in which learning takes place (e.g., outdoors, science museums, authentic research laboratories, and industry). Rapid technological developments and the easy access to information resources in all formats for many of today's students add to the mix of opportunities now available. This proliferation of learning environments raises issues such as: Do students integrate the ideas that they learn in different contexts? Do they have the skills required for autonomous learning, namely, learning to learn skills? What are effective ways and tools to scaffold learners? How can we provide rich opportunities to help socially and culturally deprived students? Responding to these issues influences the goals for learning and teaching and hence influences the design and development of new curricula.

Assessment of Learners' Achievement and Progress

In countries with centralized educational systems, policy decisions concerning the assessment of students may have a radical impact on what and how students learn. Examples of such decisions involve, for example, participation in international testing projects such as PISA and TIMSS; changes in the format of matriculation examinations (e.g., in Hungary and Israel); and decisions made by governments to implement school-based continuous assessment conducted by teachers, allowing more flexibility in the curriculum content and the instructional techniques used. In some countries, as part of educational reforms, alternative assessment methods using tools such as portfolios or e-portfolios are integrated into the curriculum process.

The Curriculum Development and Implementation Processes

Ideally, a curriculum development process should be a holistic, continuous, and long-term endeavor involving several components often carried out in parallel. Key components include initial setting of goals, analysis, and selection of the topics aligned with official syllabi; diagnosis of students' ideas as well as analysis of the inherent characteristics of the science concepts; design of learning, teaching, and assessment materials (e.g., crafting tasks, uses of representations and didactical aids); and small-scale implementation and teacher development cycles accompanied by research (teaching experiments). This process often leads to reconsideration of goals, the pedagogical resources, and the teacher development activities. Advanced stages of the process can lead to large-scale implementation and evaluation studies.

There are many open questions that require further study concerning the ways to enhance the development of useful practical and research-based knowledge relevant to curriculum development in specific topics (Kortland and Klaassen 2010), such as: How can one communicate detailed knowledge about teaching and learning sequences? How can one encapsulate and conceptualize practical knowledge of teachers? How can one develop cumulative research-based knowledge on the development of learning and teaching resources on specific topics?

Models for Curriculum Development: Initiating and Sustaining Change

Over the years, the need for changes in science teaching and learning has been raised by different interest groups such as policy makers, scientists, science educators and curriculum developers, teacher associations, and local initiators (e.g., a school, a school district, or schools networks). Pressure for change has also come from societal or socioeconomic sources.

In recent years, in many countries, curriculum change is often initiated and influenced by national and international standards and frameworks that characterize desirable change and are prepared by national academies, ministries of education (e.g., the Institute of Education in Singapore), and other organizations. Examples of such initiatives include the National Standards in Science Education developed by the US National Research Council in 1996 and revised in 2013 as the Next Generation Science Standards and the Benchmarks of Science for all Americans arising from Project 2061, developed by the American Association for the Advancement of Science. The resulting frameworks have been used for developing curricula and evaluating their quality. Teacher associations have been very influential in initiating curriculum change through the development of frameworks (e.g., the National Science Teachers Association in the USA, the Association for Science Education in the UK, the Irish Science Teachers' Association in Ireland, and the Australian Science Teachers' Association in Australia). Another mechanism for initiating change has been through influential reports discussing goals, methods, and recommendations related to teaching and learning science. Examples of such reports are the ROSE project (Sjøberg and Schreiner 2010) and *Beyond 2000* (Millar and Osborne 1998).

Calls for change have led to two key models of curriculum development efforts that differ in their methods of design and implementation and in the constituents involved in the curricular process: a center-periphery **top-down model** in which a central development group tries to influence those on the periphery and a **bottom-up model**, responding to local needs through school-based (or teacher-based) curriculum development or where change is instigated and implemented by leading teachers and then adopted by others. These two key models often differ in the nature of teacher involvement in the development process, in the activities of implementation, and in the professional development of teachers. The change processes associated with each of these models sometimes differ in the scope of curriculum adoption, in the relationship between the intended and implemented curriculum, in teacher ownership and ways of adaptation, and in the degree of sustainability. In both models, a major concern is how to prepare "educative materials," namely, materials that promote teacher professional growth in addition to student learning, and how to assure effective implementation and sustainability.

Center-Periphery Curriculum Development Models

Big curriculum projects often use a center-periphery model in which a central group develops the curriculum and then tries to disseminate it to the periphery. These groups may include in their teams teachers, science educators, scientists, and other relevant experts (e.g., experts in technology and assessment), who together carry out a comprehensive development and implementation process as described above.

In the past, curriculum change in many countries has been dominated by central governments and/or official stakeholders in charge of curriculum development and implementation, who imposed curricula and assessment methods, sometimes taken from other countries. For example, the *adoption* by developing countries of curricula and assessment methods from developed countries prevailed throughout the 1970s and 1980s and still continues. Unfortunately, these methods often lead to unsatisfactory learning outcomes because they overlook the need to *adapt* the curriculum and assessment methods to the local conditions, taking into account aspects such as the availability of teachers with appropriate CK and PCK to implement the adopted curricula; the local culture and environment (e.g., attempting to introduce advanced open inquiry in a culture where asking questions is not the norm); the availability of laboratory equipment, technology, and lab technicians; conditions for studying at home; and problems of language. Present efforts to adapt new curricula emphasize working with teachers and are more sensitive to local conditions, building on the benefits offered by the local environment and the pedagogical and educational workplace.

Some center-periphery approaches of curriculum development involve intensive ongoing collaborations among school teachers, science educators, scientists, and other relevant professionals. For example, the Salters science curricula in the UK were initiated by a group of concerned teachers, academics, and industrialists whose goal was to make chemistry more relevant to the learner. Teachers were intensively involved in the process of developing the pedagogical ideas and collecting instructional approaches. A similar model is used by the Israeli Center for Science Education in a long-term collaboration between the Israeli Ministry of Education and several academic institutions. In addition to intensive involvement in the development process, lead teachers have a central role in working with other teachers through national centers for science teachers. Learning materials resulting from such intensive teacher involvement have more potential to be adopted in schools. The involvement of leading teachers in the long-term professional development and implementation of new curricula enhances effective customizations aligned with the original rationale of the developers, yet responding to local needs.

School- and Teacher-Based Curriculum Development Models

A growing body of evidence suggests that imposing a curriculum by central professional bodies in what is called "top-down" fashion, whereby teachers are expected simply to implement the developers' philosophy, ideas, and intentions, has proved in many cases to be ineffective in introducing educational and curricular innovations into schools. One conclusion that comes out of decades of studying the success and failure of a wide variety of curriculum innovations is that imposed innovations are generally ineffective and that innovations succeed when teachers feel a sense of ownership of the innovation (Connelly and Clandinin 1988). In general, teachers tend to accept a new curriculum more easily when it is aligned with learning goals they personally value or when they perceive that the innovation provides an effective solution to problems they currently encounter. Several factors seem to be relevant for teachers in adopting curricular changes, such as judgments about the likely success of a new course, the teachers' perceptions of its effects on students' learning and attitudes, teachers' views about students' interest and motivation, perceived learning outcomes, and enhancement of self-regulated learning. The importance of supplementing the curriculum with materials developed by school teachers either in schools or districts, in the context of long-term professional development initiatives, has long been recognized.

School-based curriculum development (SBCD) can be viewed as an endeavor aimed at diminishing dependency on centralized national science curricula, increasing the schools' autonomy, and enhancing teachers' sense of ownership. A central aspect of SBCD relates to teacher professional development and entails the transfer of responsibility or ownership to the teacher. The basic assumption is that SBCD and teacher professional development are two coupled processes. Although ownership by teachers may be high in these models, often the extensive everyday demands on teachers' time and the lack of competence in curriculum development have a negative impact on the quality of change. Another aspect that has to be taken in consideration is the time that is required for the new curriculum to be implemented. Without adequate time for teachers' professional growth, it is unlikely that they will effectively develop and implement new teaching practices.

To sum up, curriculum development and change is a complex endeavor in which many factors need to be considered: the learners, the teachers, the scientific content and organization, the context of learning and teaching, the learning environments, and assessment of students' learning. Years of experience of curriculum development and change provide evidence that it is important to carry out the curriculum development process in a holistic manner that goes beyond writing textbooks and teacher guides. Rather, it should involve cycles of developing innovative learning materials and pedagogical models, implementation, teacher development, and research. There are different models for curriculum development and change that can be roughly grouped into center-periphery models and teacher- or school-based models. No matter which model is adopted, the important role of experienced teachers in the curricular process should not be overlooked. Moreover, the professional development of teachers, and providing them with opportunities and tools to customize instruction to their needs, is essential for effective implementation.

Cross-References

- ▶ Curriculum
- ▶ Curriculum Movements in Science Education
- ▶ Curriculum Structure
- ▶ Primary/Elementary School Science Curriculum Projects
- ▶ Science for All
- ▶ Teaching and Learning Sequences

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Curriculum Emphasis

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The curriculum emphasis concept was developed as a way to understand and distinguish among broadly different educational objectives that have characterized school science programs in recent history. Seven different curriculum emphases were identified originally (Roberts 1982). These were detected through analysis of school textbooks, other high-profile classroom materials, and curriculum policy statements from about –1980 in North America and England especially. A key feature of the methodology was recognizing at the outset that school science programs have two kinds of intended learning outcomes. The more obvious "content" to be learned is selected from within science, i.e., from the concepts, laws, theories, and methodologies that are the basis of scientific explanations for natural phenomena. In addition, there is *context* material that is to be learned *about* science and the reasons for learning it. The latter constitutes the curriculum emphasis. Reasons for learning science are sometimes stated explicitly and are sometimes communicated implicitly by the context.

Curriculum emphases are objects of choice, influenced by societal forces and concerns at different times in history (Roberts 1988). For example, a curriculum emphasis dubbed **Everyday Coping** permeated secondary school science textbooks widely used throughout North America in the 1940s and 1950s. In physics and chemistry textbooks, scientific principles and explanations were presented in the context of having students understand some common mechanical and electrical appliances (e.g., steam shovels, electric motors) and chemical processes (e.g., making steel). In biology textbooks the science was related to understanding aspects of the environment and to personal and public health. Overall, the message this curriculum emphasis communicates to students is that it is important to learn scientific explanations in order to demystify objects and events of fairly obvious personal relevance.

By contrast, **Structure of Science** is prominent in the high-profile classroom materials developed for secondary school science courses in North America and England during the late 1950s and 1960s. Sponsored and funded by the National Science Foundation in the USA and the Nuffield Foundation in England, these materials are silent about demystifying familiar objects and events. Instead, the message to students is about the importance of demystifying science as an intellectual enterprise. The materials concentrate on such matters as the role of mental models in developing explanations, the interplay between observations and interpretation, the reasons accuracy is important, and other aspects of the internal functioning of scientific disciplines. The emphasis remains active in science education today as NoS (nature of science).

Also in the 1960s, AAAS (the American Association for the Advancement of Science) sponsored development of a widely used science program for elementary schools that looked inward to science in another way. Known as "Science: A Process Approach," this program has K-6 students concentrate on the procedures and skills of science in a curriculum emphasis dubbed **Scientific Skill Development**. The materials are carefully sequenced to develop such "basic" skills as observation, measurement, and classification in grades K-3 and more "advanced" skills such as hypothesizing and designing experiments in grades 4–6. The message communicated to students is that the material is to be learned so that appropriate (i.e., scientific) methods can be used for developing proper explanations for natural phenomena. This emphasis is currently recognizable in school science programs (both elementary and secondary) as "scientific inquiry skills."

Two curriculum emphases are much older than those just discussed. Both are evident in school science textbooks from early in the twentieth century, but instances can be found as recently as the 1960s and 1970s. The curriculum emphasis **Correct Explanations** stresses how important it is to learn correct scientific information. The products of science (concepts, laws, and theories) are presented as correct, but very little assistance is given to help students clarify how scientific processes, skills, or reasoning are responsible for the correctness. For example, ideas that have been replaced (e.g., caloric theory of heat) are simply said to be wrong. Closely allied is an emphasis dubbed **Solid Foundation**, in which the message for students (implicitly) is that the purpose of learning the science at hand is that it fits into an overall development and sequence of ideas. In other words, the student needs this in order to get on to the next bit of the sequence. The ideas of science are presented authoritatively, in a style that resembles many university science texts (with appropriately modified language level).

At the time the original study was done, in the early 1980s, there were promising examples in several countries of a curriculum emphasis dubbed **Science, Technology, and Decisions**. This approach brings out the interrelatedness among scientific explanation, technological planning and problem solving, and decision making about practical matters of importance to society. Two high-profile examples are the "Science in Society Project" in England (developed under auspices of the Association for Science Education) and the "PLON Project" in Holland. (PLON is a Dutch language acronym for "Physics Curriculum Development Project.") As discussed below, this emphasis was a prominent component of the developing STS movement in science education.

One more curriculum emphasis was detected in the original study, although it was not very widespread at the time. As the name suggests, the message to students in a **Self as Explainer** emphasis is about the importance of a personal understanding of the process of explanation itself. Using the development and change of theories in physics and astronomy as examples, the "Project Physics" course materials developed at Harvard in the late 1960s introduce students to the influence of intellectual and cultural frameworks on scientists' ways of explaining in their own time and culture. Students can thus become more aware of the influences on their own ways of explaining events. Both constructivism and conceptual change keep this emphasis active in science education today.

Two significant changes related to curriculum emphases have occurred in the 30 years since the original study. Both are at a more general level than a single emphasis. First, science-technology-society has grown into one of the most prominent and successful movements in science education history. STS is not a curriculum emphasis. The movement has obvious roots in environmental education, of course. Indeed, some school programs call it STSE, adding an "E" at the end to call attention to the link. Also, STS/STSE has many aspects, so it is not helpful to think in terms of a single "ordinary" curriculum emphasis. It was noted earlier that **Science, Technology, and Decisions** is a component of STS; so also are portions of **Everyday Coping** and **Self as Explainer**. These three emphases – all of which "look outward" *from science* to the larger world of human affairs – were effectively sidelined in the 1950s and 1960s. The STS movement has rejuvenated them after an era dominated by the prestige of the two scientist-sponsored emphases **Structure of Science** and **Scientific Skill Development** – both of which "look inward" *toward science* (Roberts 2011).

Second, over the past 30 years the slogan *scientific literacy* has been a major topic of discussion about the overall aims and goals of school science. Like STS/STSE, scientific literacy has too many aspects to be usefully discussed as a single curriculum emphasis. Actually, the term has had so many definitions that it has come to incorporate every conceivable objective for school science programs (Roberts 2007). Thus it is tempting to think of scientific literacy as some sort of mega-blend of all seven curriculum emphases, offering students the best of each perhaps. Not so.

Instead, two distinctly different "visions" of scientific literacy have emerged. Since the early 1990s, AAAS Project 2061 has stopped using the term *scientific* literacy, in favor of the term *science* literacy. The shift is significant because, generally speaking, AAAS-type science literacy is inward looking, while scientific literacy as the term has been used historically is outward looking. The two visions have been dubbed, respectively, "Vision I" and "Vision II." The following summary shows the difference starkly (Roberts 2007, 2011).

Vision I: *Science* literacy (AAAS style) incorporates some aspects of four curriculum emphases:

- Structure of Science
- Scientific Skill Development
- Correct Explanations
- Solid Foundation

Vision II: *Scientific* literacy (historically) incorporates some aspects of three other curriculum emphases:

- Everyday Coping
- Science, Technology, and Decisions
- Self as Explainer

This discussion is not intended to suggest that one of these visions is "better" or "more correct" than the other. The visions, like curriculum emphases, are objects of choice for curriculum policy makers. Comprehending the broad array of curriculum emphases in science education history can be helpful in unpacking what is at stake in making such a choice.

Cross-References

- ▶ Companion Meanings
- ▶ Curriculum Development
- ▶ Inquiry, as a Curriculum Strand

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Curriculum Evaluation

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Keywords

Program evaluation; Science education evaluation

To understand curriculum evaluation, it is important to first understand what is meant by curriculum and evaluation. Curriculum may be interpreted broadly to mean instructional materials or processes, courses of study, and educational programs or interventions. In other words, curriculum may be considered as anything related to promoting educational growth. Evaluation may be considered a process of delineating, obtaining, and providing useful information for judging decision alternatives. Evaluation is the determination of the merit or worth of something, in this case curriculum. Evaluation can take many forms and follow several different theoretical paths, but it is a process of "valuing" and as such directly related to the perceptions of the stakeholders of the entity being evaluated. In a curriculum evaluation the stakeholders could be the designers of the curriculum, the deliverers of the curriculum, the receivers of the curriculum, and others impacted or having an interest in the curriculum. An evaluation should take the values of all of these stakeholders into account when designing, conducting, and disseminating the evaluation. Evaluation is an applied science; it needs to be used to be effective. Evaluation differs from research in terms of the motivation of the inquirer, the objective of the inquiry, the outcome of the inquiry, the role played by explanation, and the generalizability. Evaluations are almost always conducted at the request of someone and to provide information for decision making, whereas research is conducted to provide reliable information about educational matters, to identify patterns and trends that may be of educational significance, to identify factors that correlate with specific outcomes, and to seek and test explanations for them. For example, evaluation is purposefully tied to a specific object in time and space, while research is designed to span these dimensions.

There are many different approaches to curriculum evaluation. The approach taken is related to the values of the stakeholders or one group of stakeholders and is designed to assess the quality of the program though examination of the

Curriculum Evaluation, Table 1 Possible evaluation questions for curriculum evaluation

Type of questions	Possible evaluation questions
Quality of a curriculum	Are the curriculum developers doing what they said they were going to do?
	Are effective management structures in place to support participants?
	Are communication channels open and operating between providers, participants, and administration?
	Are goals understood and shared by all stakeholders?
	Are the deliverers of the curriculum well qualified?
	Is the delivery of the curriculum well planned?
	Do the participants believe they have benefited from the curriculum?
	Do the participants expect to change their behavior or attitudes as a result of the curriculum?
Outcomes of a curriculum	Has the behavior of the participants (including teachers, students, principals, and others) changed?
	Have others benefited from the changed behavior of the participants?
	Have schools been affected?
	Have student behaviors changed?
	Has student achievement changed?

Curriculum Evaluation, Table 2 Possible curriculum effects and methods of measurement for curriculum evaluation

Possible effects	Methods of measurement
Delivery of curriculum	Observations
	Participant observer
	Participant opinion
Effects on teachers	Discourse analysis
	Phenomenological studies
Effects on classrooms	Classroom observations
	Teacher logs and surveys of what takes place
	Artifact analyses
	Student or teacher opinion, surveys, and environment instruments
	Ethnographies
Effects on students	Pre-post testing of motivation, beliefs, achievement, and behaviors
	Comparison of student outcomes with outcomes from different curricula
Other effects	Case studies
	Policy analyses
	Networking analyses

program processes or the quality of the program outcomes. For example, an evaluation of a new chemistry course might address the needs of students or of their teachers or of the students' parents or any combination of stakeholder groups. Examples of evaluation questions related to the quality of the curriculum or the quality of the curricular outcomes are provided in Table 1.

The first step in a curriculum evaluation therefore is determination of what information is needed. This is a complex step that requires working closely with the commissioners of the evaluation and helping them to articulate the information they will need to make value decisions. For example, if stakeholders are not interested in whether or not students become more cooperative in class, the evaluation should not be designed to gather that information. Evaluators often use logic modeling techniques to help define how the curriculum will produce the desired effects and the consequent underlying needs for data. A logic model is a graphic depiction of the curriculum showing inputs, activities, outputs, and outcomes (Frechtling 2007). Once the desired information is delineated, questions about how best to obtain that information need to be considered. Answers to these questions are based on a variety of criteria, but the amount of time and effort that is available to be applied to the evaluation and the alignment of rigorous methodologies for data collection with the

Curriculum Evaluation, Table 3 Science curriculum examples of Stufflebeam's evaluation models

Model of evaluation	Science curriculum example
Decision/ accountability	Examining the strengths and weaknesses of a science curriculum to make decisions about how to improve the curriculum
Consumer oriented	Rating two science curricula using a set of criteria to determine which curricula is best for students
Accreditation	Evaluating a science curriculum to determine whether the curriculum meets the minimum requirements set by the state or an accrediting agency
Utilization focused	Assessing stakeholders' needs for evaluating a science curriculum and providing them with information they can use to make decisions about the curriculum
Client centered/ responsive	Working with school board members, administrators, and teachers to develop, implement, and evaluate a science curriculum
Deliberative democratic	Involving school administrators and science teachers to be part of the curriculum evaluation through collecting and interpreting the data and discussing the findings to ensure that perspectives and opinions are represented fairly
Constructivist	Partnering with stakeholders in the evaluation process to understand the different perspectives and experiences of different groups of students receiving a science curriculum
Case study	Conducting an in-depth analysis of one science class of several classes to highlight how a science curriculum is being implemented
Outcome/value-added assessment	Analyzing trends in student science assessment data to determine whether results show adequate outcomes and whether changes need to be made to improve a science program

Curriculum Evaluation, Table 4 Three examples of science curricular areas by evaluation method and questions

Curriculum area	Evaluation method	Questions the method addresses
A curriculum about making the school culture more supportive of underrepresented groups pursuing science within a school district	Case study of one or two schools	What is an in-depth description of the institutional culture at one or two schools within the district regarding science and underrepresented student groups?
	Retrospective opinion surveys of those within the school and those who interact with the schools	
	Artifact analysis of policies, procedures, and public statements over a period of time	What do administrators, teachers, staff, students, and parent think the culture of science is within their school? What do people who interact with the schools think the culture is? How has changed the culture changed?
		What changes have occurred in the policies, procedures, and expressed public image during the program?
	Ethnography	What is the culture of the classroom regarding climate change? How is the classroom culture evolving?
	Pre and post assessment of students' perceptions of climate change	How do students perceive climate change before and after participating in the curriculum?
A curriculum about climate change	Observations of the classroom by experts	What are observers' opinions of climate change before and after the curriculum and/or in comparison to other classrooms without the curriculum?
	Phenomenological studies	What are the lived experiences of a few selected students? How are students impacted by the change in implementation?
Effect of changing the implementation of a high school earth science curriculum from face-to-face to online instruction	Assessment of student knowledge and attitude and application of HLM analyses	Which individual student variables are predictive of student achievement and attitude? How much does the type of instruction contribute to the relationship?
	Value-added analysis of student scores over time	What changes have occurred in the longitudinal patterns of student achievement and attitudes since implementing the online instruction?

evaluation questions are primary concerns. Table 2 presents a sample of methods that might be used to evaluate different curricular effects.

The different methodological approaches to evaluation are grounded in different philosophies mainly along two continua: the objectivist-subjectivist epistemologies and the utilitarian-pluralist values. The objectivists rely on reproducible facts, while the subjectivists depend upon accumulated experience. Utilitarians assess overall impact, while pluralists assess the impact on each individual. These can be collapsed into two methodological approaches to curriculum evaluation: positivistic and interpretive. Positivistic methods are hypothesis driven, consider randomized control trials to determine causality as a "gold standard," and include methods such as regression discontinuity, structural equation modeling, path analyses, quasi-experimental techniques, ANCOVAs, and propensity scores. Interpretive methods are more interpretive and inductive philosophically and use methods such as case studies, life history, phenomenography, phenomenology, critical theory, ethnomethodology, symbolic interactionism, hermeneutics, semiotics, and structuralism. It is also possible to mix methods in a variety of ways and at various points of time in an evaluation.

Stufflebeam (2001) describes 22 different approaches to evaluation and recommends nine that best meet the four dimensions of the Program Evaluation Standards of the Joint Committee on Standards for Educational Evaluation (see Yarbrough et al. 2011): utility, feasibility, propriety, and accuracy. These nine approaches include three improvement- or accountability-oriented approaches, four social agenda or advocacy-oriented approaches, and two method-oriented approaches. The models are defined below and listed in Table 3 along with an example of how each could be operationalized in science curriculum education.

There is also a variety of other issues that need to be considered when conducting curriculum evaluation. One important issue is to make sure the evaluation meets all the human subjects Institutional Review Board (IRB) regulations for both the evaluator's institution and for the institutions in which the evaluation is taking place. Additionally, although logic models can be useful, it is critical that they accurately reflect how the curriculum actually operates and that they be revised as changes are made. As with all evaluations, care must be taken to conduct the evaluation in accordance with the Program Evaluation Standards (Yarbrough et al. 2011) and to provide the information to the evaluation stakeholders in a timely and appropriate manner. The evaluation information can be supplied in a variety of formats ranging from a formal report to poems written using participants' voices. The important thing is to present it in a way that the stakeholders receive an accurate picture of what was found in a manner that they find most relevant. Table 4 presents three sample curricular areas along with questions and methods that might be appropriate for a curriculum evaluation.

Cross-References

- ▶ Curriculum
- ▶ Evaluation
- ▶ Program Evaluation

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Curriculum in Play-Based Contexts

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What is Play?

The maxim that "children learn through play" is a pedagogical given in early years settings. Teachers and parents recognize that play serves many valuable purposes. It fosters children's physical, intellectual, emotional, and social development. It provides opportunities for high-level reasoning, insightful problem solving, and creative thought. Play-based curriculum is developed from the children's interests and gives rise to their creative explorations of the environment. Despite play traditionally being defined as engaging in activity for enjoyment and recreation rather than a serious or practical purpose, many educationalists have pursued other definitions. For example, Somerset (1995) wrote:

> To children, play is work, hard work, their business in life . . . This self-activated learning . . . is termed merely play perhaps because children choose what they learn, take their own time about it, and enjoy it all. (p. 15)

It has been argued that play has a quality that enables players to transform their world through their active engagement, imagination, flexible thought, and creative storytelling. They can combine and blend ideas into new creative possibilities and reinterpret familiar settings in novel ways. As such, play creates possibilities for learning. It provides a way of framing new ways of knowing, being, and relating to the experienced world. Rather than viewing play as the opposite of work and thereby associating it with limited purpose or value to learning, Davis et al. (2008) have suggested that:

> The opposite of play is… *rigidity* or *motionlessness*. In this sense, a vital quality of all living forms is play and, conversely, a likely indicator of an inert (or dead) form is lack of play. (p. 84)

As the above suggests, play then is a powerful strategy that drives learning in a dynamic, ever-changing world. It is the basis for cultivating imagination and innovation, providing opportunities to take risks, experiment, fail, and continue to play with different outcomes (Thomas and Brown 2011).

Science in a Play-Based Context

Early childhood teachers appreciate that young children are exploring and expanding the way they know about their world in a myriad of ways. They experience an environment where they develop their own workable theories for making sense of the natural, social, physical, and material worlds based on play, observation, and exploration. As Esach and Fried (2005) have argued:

> Whether we introduce children to science or whether we do not, children are doing science. We are born with an intrinsic motivation to explore the world. This means that children will be taking their first steps towards science with or without our help. (p. 332)

To ensure children's first steps toward building their understanding of science concepts are not missteps, teachers have a strategic role in planning for play and engaging in informed scaffolded interactions that create opportunities for the co-construction of knowledge as they emerge from children's interests, curiosity, imagination, and participation. The following examples are designed to illustrate these points in practice.

Example #1

The teacher watches 5-year-old Maddy banging rocks on the Nature Study table. Maddy systematically picks up a rock from the collection, studies it carefully, and then taps it on the table. Each rock is then consigned to one of two piles. "What are you doing?" the teacher asks. Maddy looks up and says "I'm listening to the rocks. These are quiet ones and these are noisy ones." The teacher looks at the two piles and sees that Maddy is classifying the rocks into loud, mostly igneous rocks and metamorphic rocks and quiet, soft, mostly sedimentary rocks. She joins Maddy in tapping rocks on the table. When they are finished, Maddy says "I wonder why these ones were quiet. Do you know?" Before the teacher has a chance to answer, Maddy sweeps the rocks into a single pile and starts sorting them again. "This time," she tells her teacher, "let's put them in their colors."

In this real-life example, the teacher developed the above experience into a project that spanned several sessions. Maddy brought photographs of a family trip to a volcanic area. The teacher took a piece of pumice (volcanic rock) to school, and they discovered that it was the only rock that floated. The teacher and several rockhounds went online together and explored other properties that scientists use to classify rocks.

This example draws attention to the novel perspectives which children can bring to exploring their world. It also illustrates the importance of the teacher's role in fostering and following the children's interests in order to help them construct new understanding. In this situation, children learned about physical properties of rocks and how scientists classify and identify them. Children also learned about floating and sinking as they tested which rocks floated and which did not. Future possibilities coevolve with the children's interest. For example, they could have designed ways to make rocks float, perhaps by building boats or attaching buoyancy devices to them. The teacher's role is to create a playful situation where the children want to learn more about a topic and are active participants in making and taking meaning from the situation. Children who are engaged in knowledge construction are involved in the interpretation of meaning, the reflection of experience, and the reconstruction of the experience to become more knowing. Playing with ideas, reinforced through exploration in practice, builds knowledge.

Example #2

The teacher asked the parents if they had any objection to her burying some bones from a sheep skeleton in the early childhood center's sandpit over the weekend. She assured them the bones were well weathered and clean. On Monday morning, several of the children headed to the sandpit with spades and diggers to start their usual excavations. They were amazed to discover "fossils." The teacher encouraged the students to uncover more bones and then to see if they could fit them together to find out what the mysterious buried creature was. They spent many hours deciding which bones went in which positions and eventually decided that they had discovered a dinosaur. The bones of *Tyranosaurus sheepi* were duly threaded together and hung on the early childhood center's fence for all to admire. It became the backdrop for adventures and the focal point for much storytelling. Indiana Jones was never such an inspiration to become an archaeologist as this teacher!

In this example, the teacher created a rich learning environment in which imagination and narrative became as important to the learning as observation and inquiry. While burying bones in the sandpit had provided an opportunity for the children to create and make meaning, the teacher directed the activity to develop the science experience. She extended the children's play over many hours and consecutive days to establish which bones were part of the skull and which were limbs. What were the functions of the various teeth they uncovered and how did they differ from the teeth the children had in their mouths? In hanging the skeleton together, the children investigated the properties of different threads – wool was too thin and broke too easily. Wire was difficult to work with but sturdy. Nylon fishing line was difficult to knot securely but easier to manipulate. The conversations, trials, and experimentations in this play setting all added to the children's learning about science.

Example #3

David was chasing after a piece of paper that was being blown around the playground. Finally he stamped on it with his foot and stopped it from moving. The teacher asked him what made the paper move. "Naughty Mr. Wind," he replied, mimicking a children's television program.

"Hmm, where's the wind coming from?" the teacher wondered aloud. David was stumped by that question as you can imagine, but by the end of the session, he had flapped his arms like wings and felt the pressure of the air all around him. He had explored running as fast as he could with a piece of newspaper in front of him and made a kite to fly. "Did you know the wind is just moving air?" he asked his mom knowledgeably when she came to pick him up.

In this example, the teacher seized the opportunity to expand David's science understanding through a series of hands-on activities and experiences. She was confident of her own science knowledge and her ability to teach about science in a variety of engaging ways. In the back of her mind was the thought that children spend many hours in front of television or computer screens without social or physical interaction with others. What impact would this have on children's play? One impact could be that technology creates a gap between effort and observable results that may mean that children are reluctant to try tasks that require real effort. Perhaps technology will promote such "magical" virtual experiences when chasing a piece of paper becomes too frustrating in the real world (Bergen 2008). Will tomorrow's children still make a game out of chasing paper in the playground?

Conclusion

Each of these examples highlights the teachers' responsibilities in managing and organizing an environment that offers a wide variety of opportunities to explore and challenge children's developing ideas. Teachers should encourage children to know what is happening and why; they should respond to children's questions thoughtfully to extend their ideas; they should help children problem solve, remember, predict, and make comparisons. An understanding of basic science concepts is important in providing teachers with the flexibility to engage children in learning about science ideas in such play-based contexts.

Cross-References

- ► Early Childhood Science Teacher Education
- ► Learning in Play-Based Environments

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Curriculum in Teacher Education

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Introduction

Curriculum most often refers to the formal documentation designed to provide guidance about what school systems, schools, and teachers should teach. It is generally produced on behalf of governments through sometimes complex processes managed by the appropriate education bureaucracy in an attempt to offer guidance about the content for (and sometimes approach to) teaching. It is, then, a product that reflects the political, cultural, and economic contexts in which it is written. This is sometimes referred to as the "envisaged" curriculum. However, many educators also recognize the existence of an "enacted" (or active) curriculum as something distinct, that is, the reality of what is actually taught, and the range of student experiences, in the classroom.

The enacted curriculum may partially reflect the belief systems and knowledge base of the teacher or local school system delivering it. Teacher education students often receive considerable instruction about the formal curriculum, to some extent because accreditation of teacher education programs is often managed by the same bureaucracy or one closely related to the one that develops the formal curriculum. Teacher education students may receive some exposure to the enacted curriculum, but this may be dependent on the particular philosophies of the teacher educators involved in teaching them in their program.

Curriculum Design

There are a number of different traditions in curriculum design and implementation, varying both with respect to time and place. The 1970s, for example, represented a period of considerable experimentation with a school-based curriculum movement evident across many English-speaking systems. Many teachers involved in this reform found it to be an exciting and challenging experience, which came alongside a number of other educational innovations, such as child-centered curricula and cooperative teaching practices. A decade later, however, there was a resurgence in the development of more prescribed national curricula with a much greater level of political control over curriculum development processes, which now came to regard teachers as agents for the delivery of curriculum. In fact these reforms quite overtly intended to reduce the control of teachers over curriculum decisions (for a thorough and interesting analysis of these historical perspectives in three English-speaking countries, see Guilfoyle (1992)).

Superimposed on these temporal variations are some significant national differences. The German *Didaktik* tradition sees the state curriculum as a broad guide to what should be taught and not as something that could or should explicitly direct a teacher's work. It takes a very "professionalized" view of the role of teachers and encourages them to exercise a degree of self-determination with some limitations on systematic and bureaucratic regulation. The Anglo-Saxon tradition on the other hand, at least over the last 20–30 years, has tended to produce curricula that are designed to be "implemented" by school systems and are intended to provide a significant level of control over how teachers do their work (Westbury 2000). These different traditions can have a significant effect on the relationship between teachers and the curriculum they are responsible for delivering.

Science Curriculum

A significant area of tension in the development of science curricula exists between the knowledge base of science and other aspects of the scientific enterprise, such as the nature of science and the complex interactions between science, society, and culture. The *Science in Society* approach, developed by the Nuffield Foundation in the UK (www.nuffieldfoundation.org/science-society), aims to provide a strong context for science learning through the teaching of important societal issues, such as cloning, genetic engineering, and global warming. *Project2061*, developed by the American Association for the Advancement of Science in the USA (www.project2061.org), includes *The Scientific World View* and *The Scientific Enterprise* as components of its *Benchmarks for Science Literacy* within a Nature of Science strand. A new national curriculum currently being developed in Australia includes *Science as a Human Endeavour* as a learning strand (www.acara.edu.au). These approaches all promise to enrich the science learning of students. However, how teacher education programs can effectively prepare new teachers with the capacity to successfully incorporate these elements into their teaching in a coherent way is still an area of difficulty with which teacher educators continue to grapple.

The resurgence of national curricula in the 1980s also saw the inclusion of laboratory work, often mandated in quite precise ways, in curriculum documentation. Laboratory work and practical experiences in general are a central part of a science teachers' life. At some levels laboratory work is a pedagogical process, designed to enhance the learning experiences of students, and for many teachers, is not seen as necessarily belonging in curriculum documentation. On the other hand, an argument can be made that it is part of the knowledge base and skill set that students should achieve. The problem that remains is the lack of an agreed understanding of what it should involve. A range of terminologies, such as "inquiry," "open-ended and first-hand investigations," "problem solving," and "experimentation," have all been used in the context of laboratory work, and it can be difficult for teachers to decipher what these terms mean in the context of their classroom practice. While the place of laboratory work in teaching, and in curriculum documentation, may seem assured, it is always under some level of scrutiny if only because of the expense of providing it in schools. Implementation of laboratory work will continue to be one of the challenging aspects of a teacher's role in putting science curriculum into action. For a recent review of these challenges in the UK context, see Toplis and Allen (2012).

Conclusion

Curriculum is a complex part of a teacher's life. While individual teachers may not feel that they have much of a role to play in the development of modern curricula, as Smith and Lovat (2003) pointed out in the introduction to their book, for any curriculum "it is the teacher, with the learners, who finally makes it work" (p. xii).

Cross-References

- ▶ Curriculum
- ▶ Curriculum Movements in Science Education
- ▶ Curriculum Structure

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Curriculum Movements in Science Education

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Keywords

Curriculum; Didaktik; Science for all; Scientific literacy; STS science

The Latin meaning of the word "curriculum" as the race course for athletic sports is a good place to start to describe the use of this word in science education. It conjures up senses of contest and of challenge that have been part of the science curriculum since its earliest beginnings in schooling. Curriculum also had a Latin meaning associating it with the "deeds and events for developing a child to an adult" that also finds resonance in how the teaching and learning of science has in some places and some occasions been conceived. It is this sense of the prescription of an intended curriculum – what is to be taught and learnt in science – that this entry discusses the science curriculum's movement over time. Others in education, and indeed in science education, use the word "curriculum" much more widely to include the pedagogies in classroom practice, the many other explicit and implicit experiences that make up schooling, but this entry uses the more restricted meaning.

The race courses for different athletic events provide some useful metaphors for the contests over the science curriculum. For example, orienteering is a race course with a few checkpoints, but no prescribed route in between. A parallel science curriculum would list a number of big scientific ideas and investigative aspects, but leave it to the science teachers to determine the detailed science they will cover to achieve the learning of these idea and aspects. The German and Scandinavian approach to the science curriculum is somewhat of this type. Again the difference between long jumping and high jumping is breadth of ground coverage versus height upwards (or negatively, depth). Science curricula influenced by the Anglo-American tradition (see below) tend to have science curricula that are quite diffuse, that is, in each year of schooling, a large number of topics are introduced, and these appear again in later years for further development. In other countries, such as Japan and Hungary, the curriculum for each year is more focused on fewer topics, but these are expected to be dealt with more completely. The difference between a long sprint like 400 m and the long distance 10,000 m can be seen in countries like USA and the Philippines which cover a disciplinary science subject in one school year, compared with European countries that devote many years to such a subject.

When the science curriculum is seen as the set of things the learners should learn, it is evident that deciding which set will be a highly contested matter among a number of stakeholders who have an interest in the shape and direction this set of learnings takes. That the science curriculum will be contested stems from many things about science and modern society. These include the strong link between science and technology (S&T) and the national economy, the critical role S&T plays in public health and environmental well-being, and humankind's curiosity about the natural world in which life of incredible variety exists and the expectation that a science curriculum could (and should) provide insights that answer and excite this curiosity. This, in turn, means that the supply and preparation of science-based professionals is of critical interest to academic scientists, who are also well aware that outstanding scientific discoveries are a matter of national pride and international competition. Within schooling there is also tension arising from the fact that science is one of the most expensive aspects of a school's budget because of its specialized laboratories, equipment, and extra professional staff.

An early example of this contest is wonderfully described by David Layton (1973) in his book *Science for the People*. In the mid-nineteenth century, a village school teacher and an educational inspector in England tried to introduce some basic science into the primary education of future agricultural and industrial laborers. There was strong resistance from a number of groups, including scientists, and the contest was lost around two issues – *science as useful knowledge* and *science as moral knowledge*.

Historically, science commonly first entered the curriculum of schooling at the senior levels only. Not surprisingly, it was taught as separate science disciplines, since its main purpose was preparing those students who had an interest in the study of these sciences at university. The contest for the content of these science curricula was dominated by academic scientists, and, as a consequence, the detailed topics for learning changed quite slowly. More scope for new topics arose as some existing ones began to make their way to lower levels of secondary schooling during the twentieth century and eventually in its last decade into the primary years. Even when the school subject in these earlier years had an umbrella title like General Science, its curriculum was usually set out as separate strands of physical, chemical, biological, and earth sciences, maintaining a strong and distinct disciplinary nature.

A major hiatus in this process for changing science content occurred in the 1930s and 1940s because of the great depression and World War II. In the aftermath of the war, during which science played a decisive part and had been developed in many ways, university scientists set about reformulating the science they taught, making it much more conceptual and hence less descriptive. A decade later it was the turn of school science, and substantial national and philanthropic funding was made available on both sides of the Atlantic for curriculum projects that would develop new materials for teaching science in schools. To be consistent and aligned with the conceptual character of university science teaching, the new materials also were to have more conceptual content, and this meant that much of the previous descriptive, applied, and historical aspects of science were deleted. With names like PSSC, BSCS, CBA, and Nuffield, these new approaches to reforming science curricula became known as the Alphabet phase.

Consistent with the view that school science teaching was introductory and preparation for study at university, the first wave of these new materials was for the disciplinary sciences in the senior years. Subsequent projects developed materials for other levels of schooling including the primary years and for nonacademic streams of students. A number of projects followed an interesting division of science and of developmental effort. The projects for the secondary levels of schooling were characterized by their use of science concepts and principles. Those for elementary or primary schooling were much more concerned with scientific processes, probably because it was recognized that many teachers at these levels had very weak science backgrounds. The Science Curriculum Improvement Study (SCIS) was an exception to this division as it did try to include both conceptual science and investigative processes.

No sooner were the new materials from the Alphabet projects available than their relevance as science curricula were challenged by an upsurge in many countries of the idea of comprehensive schooling that should meet the needs of the increasing numbers of young persons who were now in many countries continuing at school for a full secondary education. These "new students" were not attracted to the academically oriented Alphabet courses nor were they content with the alternative nonacademic ones. By the later 1970s the proportion of senior students enrolling in the sciences were declining, and educators and policymakers were looking for new possibilities to attract students to the sciences. A premature example occurred in Victoria, Australia, in 1975 when a new senior project was established to develop a single subject, covering both physics and chemistry. It emerged as *Humans and the Physical World*, where the "and" was meant to emphasize that both the interactions of scientists in producing science, and of nonscientists making use of this science in applications, were to be the source of content. This was an excitingly new conception of science at this final level of schooling, but it was then strongly opposed since, despite attracting new students, it was felt likely to reduce still further the numbers taking the traditional separate subjects. Although failing to be accepted by most schools, some of the ideas in this curriculum were soon included in the curricula for physics and chemistry.

As confusion and disappointment in the 1970s followed the major efforts of the Alphabet projects to produce new materials for school science, there were calls in a number of major reports for a "Science for All," an expression of hope that the school science curriculum would contribute to the needs of a wider population of students (see *Science for All*). As part of preparing the Canadian report, *Science for All Canadians*, Douglas Roberts, from an analysis of the Alphabet projects, introduced the idea of a curriculum emphasis or purpose (see Curriculum Emphasis). He was able to identify and describe seven of these – *Everyday Coping*, *Solid Foundation*, *Structure of Science*, *Scientific Skills*, *Correct Explanations*, *Self as Explainer*, and *Science/Technology Decisions*. He went on to argue that when one of these emphases (or purposes) becomes the criterion for selecting content for science learning, a very different curriculum results, and that if too many of them are intended in 1 year or at one level, some will fail to have an appropriate share of the intended learnings. Roberts went on to contend that as the science content changes to reflect the different emphases, so also should the pedagogy and the forms of assessment (Roberts 1988).

The idea of *curriculum emphasis* made much more explicit the implicit purposes that lay behind the contest for the science curriculum and enabled some stakeholders to be more articulate. The emphasis, *Science/Technology Decisions*, was taken up with enthusiasm in a number of countries in the 1980s, producing exciting materials to support its teaching, such as the *PLON* project in the Netherlands and *Logical Reasoning in Science and Technology* in Saskatchewan, Canada. By the end of the decade, a new movement, Science/Technology/Society (STS), for teaching science had emerged and with it the possibility of setting out the curriculum for science as a set of thematic- or issue-based modules, each occupying a significant amount of a teaching/learning year (Solomon and Aikenhead 1995) (See Science Technology and Society (STS)). This modular format enabled the integration of science content with investigation and the effect of applications, much more easily than did a list of science topics with a separate list of investigative skills.

The heightening concern for the environment during the 1980s, and the need for a hands-on practical science in the early years, meant that several other curriculum emphases became quite well established – *Science for the Environment*, *Science for Technologies*, *etc*.

Soon after, and independently, a number of older subjects like Art & Design, Industrial Arts, and Domestic Science became linked with the emerging computer technologies to be newly defined under the subject umbrella of Technology. This was a setback to the STS type of curriculum thinking since "Technology" was now a curriculum term in its own right, but with a different meaning than it had as "applications of science" in STS, providing the bridge between Science and Society. This, together with the emergence of a new slogan, "scientific literacy" (perhaps to catch some of the priority being given to numeracy and literacy in the primary years), meant that the science curricula of the 1990s were more concerned with establishing science content throughout all the years of schooling using rather traditional approaches, than with giving it a new direction. These later redefinitions of a curriculum for school science, unlike the earlier ones that were just for science at a particular level (or levels), were carried out as part of a total reform of the compulsory school curriculum. A prevailing market view of social practices promoted a template approach to listing each subject's curriculum. The horizontal levels in this template are the years of schooling, and the vertical ones are disciplinary stranded lists of science content and of science processes. Such an expression of the curriculum gives a false air of progression of learning and lends itself to simplified external forms of assessing learning (and of teaching) that are part of the accountability that the market view requires. This approach is, however, at the expense of the intended integration of these strands and of the denigration of those newer goals of the science curriculum that are not accessible to external assessment. Millar and Osborne (1988) provide a helpful critique of this still prevailing approach to the science curriculum in the report, *Beyond 2000*.

"The curriculum" is a familiar term in countries in which education has been primarily influenced by British and American patterns and values of education (the Anglo-American tradition). In countries more influenced by European educational traditions, words like the German, *Bildung* and *Didaktik*, are more familiar. Conversations between representatives of these two traditions in the 1990s helped to clarify some quite significant differences that have a bearing on "what learnings" should be included in science education (Hofmann and Riquarts 1995) (See Didaktik).

In Anglo-American contexts, the curriculum for the sciences has, as its primary goal, been directed to the purpose of introducing students to the basic concepts, principles, and investigative procedures of the various sciences and, in this way, preparing those students who choose to continue science-based studies beyond school. In the European tradition, a primary purpose of school education, and hence of the sciences in this education, is quite explicitly about the maturing of students as whole personalities. Since the various fields of science have developed to serve purposes that are different from this, their bodies of knowledge are not automatically useful in schooling. In the first tradition, the responsibility for the content learning in the science curriculum is usually held centrally, but in the second tradition the individual teacher takes more of this responsibility.

This difference in tradition was very evident in the early 1990s when many countries were redefining their whole school curriculum or their curriculum for science(s). In the Anglo-American countries, there was much concern with identifying Key Learning Areas. Science, as a set of science disciplines, or as combined in some way, was always one of these KLAs. At the same time the Norwegian Government adopted in 1994 the **Core Curriculum** which defined itself not in terms of KLAs or subjects, but as a set of human characteristics that education should strive to develop – *Spiritual Human*, *Working Human*, *Aesthetically aware Human*, *Environmentally responsible Human*, *Social Human* and *Integrated Human*. It is possible to find many learnings in the sciences that would contribute to each of these aspects of a rounded person, but how to structure these into a program for the years of schooling proved very difficult, even in Norway. Nevertheless, the **Core Curriculum** serves as a reminder that a science curriculum should aim to serve educational purposes that are much wider than it often does.

After lying fallow through the 1990s, but again in response to recent evidence from the two international assessment projects TIMSS and PISA of a decline in student interest in science, the ideas of STS are reemerging as science curricula begin to include Context-based Science and Socio-scientific Issues Science. These international projects are conflicting in the sense that TIMSS is concerned with comparing the curriculum content that is common across countries – an inevitably conservative view – whereas PISA, not primarily curriculum oriented, has pushed for students' active use of scientific knowledge in everyday contexts.

In the last decade or so, several of these other emphases have gained strong support among a number of science educators and their innovative teacher colleagues –*Scientific Argumentation*, *Context-based Science*, *Socio-scientific Issues Science* – each of which can also be recognized as developments of the STS movement but in terms of the S, T, and S, respectively. Roberts' early emphases could be accommodated within the teaching of individual science or in more integrated science teaching, but some of these more recent emphases only make sense within an interdisciplinary view of science teaching, since real-world contexts and SSIs rarely involve just a single science discipline.

A recent challenge to the science curriculum has come from stakeholders who see the impact of the digital revolution on society being so great that knowledge is becoming more of a verb than the noun it has formerly been. This Knowledge Society emphasizes skills like *thinking*, *creating*, *communicating*, *problem solving*, *knowing how to learn*, *etc*. These are being described as generic, but they challenge the science curriculum which has hitherto been much more concerned with students acquiring a store of established knowledge and standard procedures than with these more dynamic practices, despite the importance they have in science itself. New science curricula in New Zealand and Australia have been much concerned with how this new challenge is best accommodated.

Cross-References

- ▶ Context-Led Science Projects
- ▶ Curriculum Emphasis
- ▶ Didaktik
- ▶ Inquiry, as a Curriculum Strand
- ▶ Science, Technology and Society (STS)

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Curriculum Organisation

- ▶ Curriculum Movements in Science Education
- ▶ Curriculum Structure

Curriculum Projects

- ▶ Context-Led Science Projects
- ▶ Curriculum Movements in Science Education
- ▶ Primary/Elementary School Science Curriculum Projects

Curriculum Structure

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Keywords

Curriculum design Curriculum models; Curriculum frameworks

The nature and purpose of science education as a component of the school curriculum have a contested history. For example, DeBoer (2000) identified "scientific literacy" as a common curriculum goal for science education but over time there has not always been a shared meaning of that term. In any event, such a goal can be expressed in curriculum terms in different ways. Curriculum structure is therefore as much a social construct as it is an objective description of the shape and function of a particular curriculum. Disagreements over curriculum structure have often reflected deeper philosophical and political differences about epistemology and the purposes of schooling.

In this entry, curriculum structures will be reviewed paying attention to the multiple senses in which the term is often used: first, as differences in curriculum form; second, as different ways of making scientific knowledge accessible; and third, as an aspect of society's expectations of scientific learning. These different ways of viewing curriculum structure are often underpinned by theories of different kinds and these will also be referred to.

Curriculum Structure as Form

Posner (1974) referred to the many different ways in which the curriculum could be structured: these structures depend on the theoretical disposition of the author, the particular social and political context of the time, and the purposes that a school subject like science is meant to serve. Thus, when the acquisition of scientific knowledge, or learning to "think like a scientist," is seen to be important, the focus of school science subjects will be the science disciplines themselves. This is almost always the case at the senior levels of schooling, but arguments have also been made for younger students to be introduced to science disciplines so they can be adequately prepared to become scientifically literate and have the very real option of taking up a scientific career. The structure of such a curriculum is likely to be topic based, linked to individual science subjects, and characterized as the traditional academic curriculum. Pedagogy is likely to consist mainly of direct instruction.

Psychologists such as Jerome Bruner have suggested that the key concepts of the academic disciplines, whether in science or social science, can themselves form the basis of a school curriculum. Such concepts can be visited and revisited at different stages of schooling so that students can develop a deeper and deeper understanding of them. The resulting curriculum structure is likely to focus on the major concepts in one or more academic subjects and the ways of thinking that characterize that subject. Bruner's views on learning led him to argue that such a curriculum would also highlight students' active engagement with the subject. Thus, while its focus would be the academic disciplines, its pedagogy was more linked to discovery learning.

For other curriculum theorists, such as John Dewey, there needed to be a more integrated approach to knowledge in the school curriculum, and this thinking has had a considerable impact on science education. Integrating knowledge from different science disciplines has been a popular approach to science curriculum development. Key ideas of different kinds can be used as curriculum organizers, such as social issues (e.g., sustainability and environmental degradation) or health issues (e.g., water quality in developing countries) or issues concerning the application of science in society (e.g., the role of nuclear energy). In this form of curriculum organization, scientific knowledge is not abandoned but it is applied in different ways to address important social issues. It is these issues that form the basis of the curriculum. Accompanying pedagogy is likely to be inquiry oriented.

A related curriculum structure to that of the integration of scientific knowledge has been supported by the Salters' Institute for Industrial Chemistry in the United Kingdom. It is based on the identification of everyday contexts, sometimes called authentic contexts, that require both social and scientific knowledge to understand them (Campbell et al. 1994). The importance of such contexts is that they should have particular relevance to the lives of young people. This approach to scientific understanding is reflected in large-scale assessments such as the Programme for International Student Assessment (PISA) but also in curriculum developments in several countries including the United Kingdom and the United States. In a sense, this approach to science curriculum is not so much built on integrating knowledge from different disciplines (although it does this) as bringing together scientific and social explanations for important phenomena influencing young people. Students learn science and its processes but as well and they learn about its social applications in relevant contexts (Solomon and Aikenhead 1994). The curriculum is structured around relevant social contexts that require scientific and social explanations and pedagogy is likely to be inquiry oriented.

Ways of Knowing and Learning Science

It is clear from the above descriptions of different forms of science curriculum that, while they represent different curriculum forms and structures, they are by no means value neutral. Discipline-based approaches assume that scientific knowledge within disciplines should be transmitted exactly in that form to students, and this is why such approaches are usually associated with a pedagogy of direct instruction. Bruner's version of this discipline-based approach both changed the nature of science (from facts to concepts) and saw the need to develop a more engaging and meaningful pedagogy. Integrated curriculum designs did not deny the importance of scientific knowledge but sought to draw on multiple disciplines where they were relevant in addressing particular issues. Authentic context-based approaches went further still by linking the curriculum to daily living and the application of scientific and social knowledge to addressing issues of immediate relevance to students. This trajectory from the disciplines to contexts is not so much about the nature of science as about the ways young people can best access scientific knowledge. If it is assumed that in a democratic society all students ought to have access to key knowledge about science, then different curriculum structures can be seen as different ways to achieve this objective.

It is for this reason that approaches to pedagogy have been referred to alongside each description of a particular curriculum structure. If knowledge is believed to be fixed and static as embodied in the scientific disciplines and only has to be "absorbed" by students, then direct instruction will be the pedagogy of choice. If students themselves need to integrate new knowledge into their existing knowledge structures, then learning processes will need to provide the opportunity for this. There is no single pedagogy that can be prescribed, but, where issues and problems form the structure of the curriculum, then inquiry or problem-based pedagogies will work best. So the "what" and the "how" of science learning are closely related.

Society's Expectations About Science Learning

Schools operate in social and political contexts so it should not be unexpected that what is taught and how it is taught will be of interest to society at large. In the post-World War Two period, the relationship of science to national security led to a focus on the strategic and instrumental purposes of teaching science, and the "race to space" in the 1960s highlighted the need to produce scientists who could assure victory in this race. Thus, the focus on scientific disciplines and Bruner's concept-based curriculum is that students needed to understand "real" science. At the same time, some community groups have often advocated for more “rigor” in the curriculum, and this is generally seen to be achieved with a discipline-based approach to school subjects. It is in this sense that curriculum structure can be said to be socially constructed because it is a response to social pressures.

Yet these social pressures can change. For example, when governments change, there can also be a change in educational philosophy and direction. This can then create spaces for alternative curriculum structures that may be more student focused or more supportive of adopting structures and pedagogies that are known to meet the needs of a broader range of students. Educators themselves can be responsible for promoting these alternative approaches especially where they can show there will be benefits for all students rather than just some. It is important to understand that curriculum structures can be used for important social purposes as well as educational purposes.

Conclusion

Curriculum structures give shape to the form the curriculum takes, but this form may be determined as much by social influences as educational rationale. Choice in curriculum structure ranges from the use of pure science disciplines to the selection of scientific knowledge that addresses issues of immediate relevance to students. Related to this choice are questions of pedagogy and how students can most effectively learn science. Society will always maintain an interest in the form and structure of the science curriculum so that changes can be expected over time and in response to what are seen as key social and political priorities.

Cross-References

- ▶ Curriculum
- ▶ Curriculum Development
- ▶ Curriculum and Values
- ▶ Dewey and the Learning of Science

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Cut Scores

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Keywords

Cut scores; NAEP; Test; TIMSS

Cut scores are points on a distribution of scores representing the minimum scores required for performance at specific levels. They are used to categorize performance on assessments into each of the performance levels. In high-stake tests the cut score becomes the passing score determining either passing or failing the test.

The measured achievements have to be considered as continua. Dividing each of these continua is essentially arbitrary. The result consists in a number of divisions (cut points) that mark the boundaries of the divisions. The establishment of cut scores represents one of the most critical test development issues, especially for test with any consequences for examinees. Standard-setting methods used to determine cut scores require expert judgments about the expected performance at each level. The cut scores determining each level are available with the descriptions because there is a need of reporting student performance not just as scores, but also in terms of content; the usefulness of the data collected can be proved when there is an understanding of what is measured and its connection to what these measures reveal about students.

In Trends in International Mathematics and Science Study (TIMSS), there are selected four cut points, 625, 550, 475, and 400, on the achievement scales. These cut points corresponding to the international benchmarks were selected initially to be as close as possible to the percentile points – 10 %, 25 %, 50 %, and 75 %. The National Assessment of Educational Progress (NAEP) uses a set of cut scores on the scale that defines the lower boundaries of basic, proficient, and advanced levels being determined for each grade through a standard-setting process.

Cross-References

- ▶ Achievement Levels
- ▶ High Stakes Testing
- ▶ National Assessment of Educational Progress (NAEP)
- ▶ Scale Scores
- ▶ Third International Mathematics and Science Study (TIMSS)

D

Designed-Based Research

▶ Evidence-Based Practice in Science Education

Designing and Assessing Scientific Explanation Tasks

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Argumentation; Assessment; Inquiry; Modeling; Rubrics; Scientific Practices

The goal of science is to explain phenomena, reoccurring natural events that happen in the world. As such, scientists strive to understand how and why phenomena occur. All explanations begin with a need to find an answer to a question. A claim is frequently made in response to a question. In order to test these different claims, scientists often design and carry out investigations that allow them to collect data or they may use data that already exists. Scientists also use theoretical ideas to provide justifications for why the evidence supports or refutes these various claims. In constructing these explanations about the natural world, scientists engage in argumentation in which they debate competing claims by evaluating the validity of those claims and the supporting evidence. Here is where evidence and scientific principles play an important role. In science, the claims that best fit with the available evidence and scientific principles move forward in the community. When new evidence emerges that the claim cannot account for, claims are revised, producing a new explanation. As the Framework for *K-12 Science Education* argues, "Deciding on the best explanation is a matter of argument that is resolved by how well any given explanation fits with all available data, how much it simplifies what would seem to be complex, and whether it produces a sense of understanding" (NRC 2012, p. 68). The focus of the framework (NRC 2012) and the Next Generation of Science Standards (NGSS 2013) is for students to construct explanations based on evidence and scientific ideas.

To support students in constructing scientific explanation, McNeill and Krajcik (2011) suggest using a framework that consists of a claim, evidence, reasoning, and rebuttal. The framework supports students in constructing and critiquing explanations. The claim, evidence, reasoning, and rebuttal framework (CERR for short) can be used to develop explanation assessment tasks as well as analyze student explanations. The framework was adapted from Toulmin's (1958) work on argumentation. In writing explanations,

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students propose claims and support those claims with evidence and reasoning that provides a justification for that link between the data and the claim. They also need to argue why other claims don't fit the evidence as well as the claim they put forth, which is where the rebuttal frequently is incorporated.

The claim is a statement that expresses the answer or conclusion to a question or problem. When a question is posed, information is sought to provide evidence and justification for the claim or an investigation is planned to provide evidence to support the claim. As such, constructing an explanation can engage learners in other scientific practices such as designing investigation, analyzing and interpreting data, and arguing form evidence.

The other components of the scientific explanation framework provide the support and backing for the claim. A central feature of science is its use of scientific data as evidence to understand the natural world (National Research Council 2007). Evidence is scientific data that provided support for the claim. Data can come from observations and measurements from natural settings or from the results of controlled experiments. When constructing explanations, data can either be first or second hand. Firsthand data is data collected and generated by investigations planned by the experimenter. Secondhand data was collected and generated from investigations planned and conducted by other researchers. The accuracy or reliability of scientific data is often checked through multiple trials or by comparing different types of data. Students can either collect data themselves or be provided with data such as data tables, readings, or a database.

There needs to be appropriate and sufficient data to justify the support of a claim. Appropriate data need to be scientifically pertinent and important for supporting the claim. Sufficient data means that enough data has been generated and gathered to support the claim. Typically in science, we collect, analyze, and use multiple pieces of data to answer a particular question or problem.

Reasoning provides a justification that shows a way the data can be used as the evidence to support the claim. The reasoning states why the evidence supports the claim, providing a logical connection between the evidence and reasoning. Reasoning also requires discussing appropriate scientific principles to justify why the data can be used as evidence to support a particular claim. In explaining phenomena, there are multiple plausible explanations for how or why a phenomenon might occur. Often scientists need to provide an argument about which claim is the most appropriate. The rebuttal provides evidence and reasoning to rule out other possible alternative claims and provides evidence and reasoning for why the alternative is not the appropriate explanation for the question or problem. Scientists consider and debate these multiple possible claims.

Construction Scientific Explanation Tasks: How can you design and evaluate tasks to assess students' abilities to construct scientific explanations? How can explanation assessment tasks be designed to align with the key science ideas? Designing and judging assessment tasks that focus on scientific explanations will assess students' understanding of the structure of scientific explanations and disciplinary core ideas (NRC 2012). The claim, evidence, reasoning, and rebuttal framework provides structures for designing and assessing explanation tasks. McNeill and Krajcik (2011) and Krajcik et al. (2008) propose a process for developing scientific explanations assessment tasks. The process consists of seven steps:

Step 1: Identifying and unpacking the science ideas
Step 2: Selecting the level of complexity of the task
Step 3: Developing performance expectations
Step 4: Constructing the assessment task
Step 5: Reviewing the assessment task
Step 6: Using the base rubric to develop a specific rubric

Selecting and Unpacking Science Ideas: The first step entails selecting and unpacking the science ideas. National or state documents that specify what learners should know and that target disciplinary core science ideas addressed in the classroom can be used for selecting the science ideas. Examining documents and selecting the appropriate science ideas can help determine what specific science ideas are key for building scientific understanding necessary for problem solving and explaining phenomena.

After selecting the science idea, the ideas need to be "unpacked." Unpacking has two components. First, a science standard often contains many different science ideas. In order to develop a thorough understanding of the standard, it helps to break it down into related science ideas and to clarify each science idea in terms of its meaning and relationship to the other ideas. Second, it also helps to consider common student nonnormative ideas or challenges in learning the science ideas. The unpacking process helps to clarify what science ideas to target in the item as well as common student difficulties to incorporate into the item.

Selecting the Level of Complexity: The next step in designing scientific explanation assessment tasks is to select the level of complexity. Here, a decision on the level of complexity of the framework as well as difficulties students might experience when constructing explanations needs to be made. Level of complexity refers to the number of components and variations in those components that students will need to incorporate when responding to the task. Students could respond to only the first three components (e.g., claim, evidence, and reasoning), or the fourth component of rebuttal could also be included. Next, the level of difficulty for each component needs to be decided. Typically, the claim is at the simplest level.

Usually, the variation in the difficulty of the components occurs in varying the complexity of the evidence and reasoning. The amount of evidence and reasoning can vary from simple to complex. At the simple level, the evidence supports the claim, and at the moderate level, evidence that is appropriate and sufficient needs to be given. At the complex level, multiple pieces of sufficient and appropriate evidence need to be provided. Reasoning at the simple level provides a justification to support the claim and at the moderate level a justification of why the data can be used as evidence to support the claim using appropriate scientific principles. At the complex level, reasoning requires a justification of why the data can be used as evidence to support the claim using appropriate scientific principles for each piece of evidence. The rebuttal is only appropriate at the complex level and requires that counterevidence and reasoning be given to argue why possible alternative explanations are not appropriate. (See McNeill and Krajcik (2011), for a more complete description.)

Creating Performance Expectations: A performance expectation specifies a learning goal beyond the content knowledge that students are to learn by specifying how they will apply the science ideas (Krajcik et al. 2008; NRC 2012). In this respect, performance expectations specify how students will make use of the science ideas. Although a variety of active verbs can be used to describe how students will use science ideas, the use of scientific and engineering practices – designing an investigation, analyzing and interpreting data, constructing scientific explanations, arguing from evidence, and building models (NRC 2012) – specifies learning goals and what is hoped students will do in terms of important capabilities in science. This discussion focuses on the practice of constructing scientific explanations; however, the construction of other types of assessment tasks can use this process for developing a variety of assessment types.

A performance expectation is developed by crossing the scientific practice of explanation with a science idea of interest. Figure 1 shows a representation and gives an example of this process. Developing performance expectations provides explicit statements of learning goals that guide the design of learning tasks, assessment tasks, and the associated rubrics. Notice that in Figure 1, the performance expectation clearly states the expectations for the claim, evidence, and reasoning. The performance expectation specifies the science idea and how learners should use that knowledge, in this case constructing an evidence-based explanation about pure substances having characteristic properties. The performance expectation specifies the complexity of the evidence and reasoning that needs to be included in the assessment task.

Practice	Science idea from the framework for K-12 science education (NRC 2012)	Performance expectation
Scientific explanation	Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it	Develop a scientific explanation with a claim that a pure substance has characteristic properties, two pieces of appropriate and sufficient evidence and reasoning that a substance has the same molecular composition and structure throughout and that other substances with different properties do not have this same structure and composition

Designing and Assessing Scientific Explanation Tasks, Fig. 1 Creating performance expectations. Scientific practice crossed with science idea to make a performance expectation

Sample	Density	Color	Mass	Melting point
1	1.0 g/ml	Clear	6.2 g	0.0 C°
2	0.89 g/ml	Clear	6.2 g	38 C°
3	0.92 g/ml	Clear	6.2 g	14 C°
4	0.89 g/ml	Clear	10.6 g	38 C°

Designing and Assessing Scientific Explanation Tasks, Fig. 2 Assessment task aligned with performance expectation. John measured the properties of several materials described in the data table below. He was confused because three of the samples had the same mass but different melting points and density. Using the data in the table, write a scientific explanation about whether any of the samples are the same substance. Make sure you include a claim, at least two pieces of evidence, and reasoning to justify your position

Developing the Assessment Task: Developing performance expectations provides specifications for constructing assessment tasks or learning activities to meet performance expectations. Performance expectations help to develop alignment among learning goals (the performance expectation), the learning tasks, and the assessment tasks. Figure 2 provides an assessment task that aligns with the performance expectation in Figure 1.

In writing the assessment task, identification of a context that is accessible to learners must also be taken into consideration. The context includes determining the phenomenon addressed in the task and the data students analyze and interpret to justify their claim. An appropriate context makes the task accessible to students. The assessment task in Figure 2 provides a phenomenon and science ideas that are accessible to middle school learners. The context also is important because scientific explanations are written to makes sense of specific phenomenon. In the example in Figure 2, it is about properties of a specific substance.

The task in Figure 2 would require middle school students to make the claim that samples 2 and 4 are the same substance because they have the same density and melting points. Their reasoning would include that density and melting point are properties that don’t change with the amount of sample. The students would also need to specify that the reason why the density and melting points are the same regardless of amount is because the samples are made of the same types of molecules throughout both samples. Samples 1 and 3 are not the same substance even though the samples have the same mass because mass is not a characteristic that can be used to identify a sample as one type of substance or another. In responding to this item, students also have to engage in interpreting data; as such, this task engages students in a secondary scientific practice of data interpretation.

Review the Assessment Task: Assessment tasks need to be reviewed to check if the science ideas specified in the task are necessary and sufficient for responding to the tasks. The task also needs to be reviewed to assure that the assessment task is comprehensible to learners. The Project 2061 assessment evaluation framework (DeBoer 2005) provides an appropriate process for accomplishing this step. The Project 2061 assessment framework focuses on three criteria: necessity, sufficiency, and comprehensibility. Answering three questions focuses the review:

1. Is the knowledge necessary to correctly respond to the task?
2. Is the knowledge sufficient by itself to correctly respond to the task or is additional knowledge needed?
3. Is the assessment task and context likely to be comprehensible to students?

The necessity criterion examines if students need to apply the science ideas and the scientific practice intend by the assessment task to appropriately respond to the item. In many respects, unpacking the science ideas and specifying the performance expectation helps to ensure if the science ideas and scienttific practice are necessary to provide a response to the item.

The sufficiency criterion considers what other science ideas or scientific practice is included in the assessment task and if that additional knowledge is appropriate to include. As such, the sufficiency criterion provides a check if other science ideas or scientific practices go beyond those specified in the learning goal. If the assessment task includes science ideas or scientific practices that the learners have not developed, then learners are likely to respond inappropriately to the item not because they don't have an understanding of the target goals but because they don't know these additional science ideas or practices used in the task. If learners have previously studied this additional content, it might be appropriate to include. For instance, to respond appropriately to the assessment task in Figure 2, students also need to know that density and melting point are properties of a substance but that mass is not a property of a substance. They also need to know how to read a table and interpret the data in the table. The additional science ideas and the level of data interpretation are appropriate for middle school science.

The comprehensibility criterion considers if the assessment item is appropriately written to meet the experiences and background knowledge of the learners. In the section on developing the assessment task, the appropriateness of the phenomena and science ideas were considered. In determining if the assessment task and context are likely to be comprehensible to students, students' cultural backgrounds and the literacy demands of the task also need to be taken into consideration. If the reading demands are beyond those of the students, the students might know the target learning goals but respond inappropriately because of the language. Consideration of cultural backgrounds is essential as learners from various backgrounds could have difficulty interpreting the context of an assessment task.

Using the Base Rubric to Develop a Specific Rubric: A base explanation rubric (see Appendix 1) provides a general rubric for evaluating scientific explanations for various science ideas (McNeill et al. 2006; McNeill and Krajcik 2011). The base rubric includes the four components of a scientific explanation and provides guidance about developing different levels of student achievement for each of those components in a specific rubric. The specific rubric combines both the general structure of a scientific explanation and the appropriate science ideas and evidence for the particular task. Adapting a base rubric to develop a specific rubric involves aligning the rubric to a particular assessment task. The specific rubric is designed to a particular explanation task and shows what science ideas and evidence the students needs to apply at each level of achievement. The specific rubric includes determining what would count as an appropriate claim, evidence, and reasoning. When applicable, it also needs to include specifying the alternative explanations and the evidence and reasoning to support refuting the alternative claims. To develop a specific rubric, begin by using the base rubric and constructing the ideal student response for each component.

Summary Statement: To support students in constructing scientific explanations, McNeill and Krajcik (2011) suggest using a framework that

Designing and Assessing Scientific Explanation Tasks, Appendix 1 Base Explanation Rubric

	Level		
Component	0	1	2
Claim: A response to the original question	Does not make a claim, or makes an inaccurate claim	Makes an accurate but incomplete claim	Makes an accurate and complete claim
Evidence: Scientific data that supports the claim. The data needs to be appropriate and sufficient to support the claim	Does not provide evidence, or only provides inappropriate evidence (Evidence that does not support claim)	Provides appropriate, but insufficient evidence to support claim. May include some inappropriate evidence	Provides appropriate and sufficient evidence to support claim
Reasoning: A justification that links the data to the claim. Reasoning shows why the data counts as evidence by using appropriate and sufficient scientific principles	Does not provide reasoning, or only provides reasoning that does not link evidence to claim	Provides reasoning that links the claim and evidence. Repeats the evidence and/or includes some scientific principles, but not sufficient	Provides reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles
Rebuttal: Communicates possible alternative explanations and provides evidence and reasoning for why the alternative explanation is not appropriate	Does not communicate alternative explanations exist or makes an inaccurate rebuttal	Communicates alternative explanations and provides appropriate but insufficient evidence and reasoning in making the rebuttal	Communicates alternative explanations and provides appropriate and sufficient counter evidence and reasoning when making rebuttals

Adapted from McNeill and Krajcik (2011)

consists of a claim, evidence, reasoning, and rebuttal. The framework assists students in constructing and critiquing explanations as well as supports teachers and designer in designing explanation learning tasks and explanation assessment items. In writing explanations, students propose claims and support those claims with evidence and reasoning that provides a justification for that link between the data and the claim. They also need to argue why other claims don't fit the evidence as well as the claim they put forth. A six-step process that begins with identifying and unpacking key science ideas and ends with developing a specific rubric provides a technique for developing explanation assessment items that align with the target core science ideas and will help ensure that assessment items are appropriate for the background experiences and prior knowledge of students.

Cross-References

- ▶ Argumentation Environments
- ▶ Assessment of Doing Science
- ▶ Assessment of Knowing and Doing Science
- ▶ Formative Assessment
- ▶ Inquiry, Assessment of the Ability to
- ▶ Summative Assessment

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Designing and Assessing Scientific Modeling Tasks

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Keywords

Argumentation; Assessment; Inquiry; Modeling; Rubrics; Scientific Practices

Scientists strive to provide causal accounts that explain and predict phenomena. Scientists use models to represent relationships among components to test and explain complex phenomenon. As such, modeling is an integral and common practice across the science disciplines. Scientists continually form, test, evaluate, and revise models to explain and predict phenomena. By testing models against data, scientists evaluate and revise models to better fit the data. When a model can no longer account for the data, the model is revised.

> Observations of the natural world motivate the construction of models, which in turn motivate further observations and drive the resulting interpretations. In this way, models become explanations: that is, stipulations of possible cause and effect relations in the phenomenon under investigation. (Penner et al. 1998, p. 430)

Defining Scientific Modeling

The practice of scientific modeling differs significantly from the way models are often thought of and talked about in everyday life. For example, a model airplane is usually a smaller version of an actual plane. In this colloquial use of the word, a model is a scale representation of an object. However, scientific modeling is more complex and abstract process. A scientific model does include representations, but it does not it is representing. A model may include invisible components including symbols to indicate the relationships among the components of the model. Although scientific modeling can include representations that look similar to the system that is being modeled, it can also include mathematical representations, graphs, and computer simulations.

All models need to explain and predict phenomena and be consistent with scientific theory; in other words, the model must help explain what, how, or why a phenomenon occurs. Moreover, models need to specify the relationships among components in the system that is being explained to provide a causal account. Scientific modeling is also an iterative process. A scientist will create a model to explain a phenomenon. The model is then used to make predications about related phenomena. Those predications are tested and used to revise the model. The model is refined to design a more robust explanation. The model continually evolves with additional evidence.

One model will not be able to capture all aspects of a phenomenon. In fact, models often simplify the system in order to highlight certain aspects. Thus, different models may be needed to explain different aspects of one particular phenomenon. For example, a lightning strike is a complex phenomenon. One model could highlight movement of particles in the air to explain how large charges build up in thunderstorms. Scientists would use another model to explain why light and sound are observed when the lightning strikes. A different model is needed to predict the likelihood that certain weather systems will lead to lightning strikes. Finally, scientists would use a mathematical model to triangulate locations of strikes using information about where and when they were observed. Scientific modeling is a complex process that requires analyzing a variety of evidence and utilizing theory to explain and predict phenomena.

Modeling in Science Classrooms

Scientific modeling is one of the scientific practices identified in the Framework for K-12 Science Education that should be used in conjunction with disciplinary core ideas and crosscutting concepts to help learners form usable understanding of science (National Research Council 2012). The various scientific practices work together to help build our understanding of the world. For instance, scientists often argue that one model better fits the data than another model. Although developing and using models is central to the practice of science and as such should be an important aspect of what occurs in science classrooms, developing, testing, and revising models are seldom seen in the science classroom.

The models that students develop are concrete artifacts that can be shared and critiqued by others. These artifacts provide a window into students' mental models or their understanding of this area. When students develop and test models to explain and predict phenomena, the process of developing models helps learners form integrated conceptual understanding. Integrated conceptual understanding refers to concepts and connections that students hold and use to represent and explain his or her understanding of phenomenon in the world. Models can be drawings, three-dimensional structures, a set of equations, qualitative descriptions, or a simulation.

Supporting Students in Building Models

Due to the complex nature of the practice of scientific modeling, teachers and curriculum designers need to support students in the process by providing criteria for developing a scientific model. Although models are used in a variety of ways, there are similar elements across models:

1. Identification and specification of the components or variables important for the analysis of the system.
2. Description or representation of the relationships or interactions among the components or variables.
3. The collection of relationships provides a causal account of the phenomena under study.

Even a mathematical model includes these elements. For example, $F = ma$ includes variables to represent the amount of force, mass, and acceleration of an object or system of objects. The equation indicates several relationships among these variables. Finally, the equation serves as a model, when it provides a causal account of the phenomena. The equation alone is a simple algebraic statement; however, it serves as a model if it is used to explain observations or make predictions about the motion of one or more objects.

Designing Assessment Tasks for Scientific Modeling

The Framework for K-12 Science Education (NRC 2012) and the Next Generation Science Standards (Achieve 2013) define science learning expectations as the blending of scientific practices, crosscutting concepts, and disciplinary core ideas to form performance expectations. A performance expectation defines knowledge in use. Assessing scientific modeling requires the use of scientific ideas. A performance expectation for modeling is developed through crossing the practice with disciplinary core ideas and crosscutting concept. Finally, a relevant phenomenon is added so the performance expectation will lead to a rich assessment task.

Clear and specific performance expectations provide guidance in writing an assessment task as they point out important elements that need to be included in the assessment. Table 1 shows an example of a performance expectation. The performance expectation shown in Table 1 contains two critical elements: (1) the scientific practice of developing a model and (2) the use of a disciplinary idea – the structure of an atom. This specificity supports the alignment between the performance expectation and the assessment task. Figure 1 shows an assessment task that aligns to the performance expectation in Table 1. The performance expectation and assessment task are appropriate for ninth or tenth grade physical science.

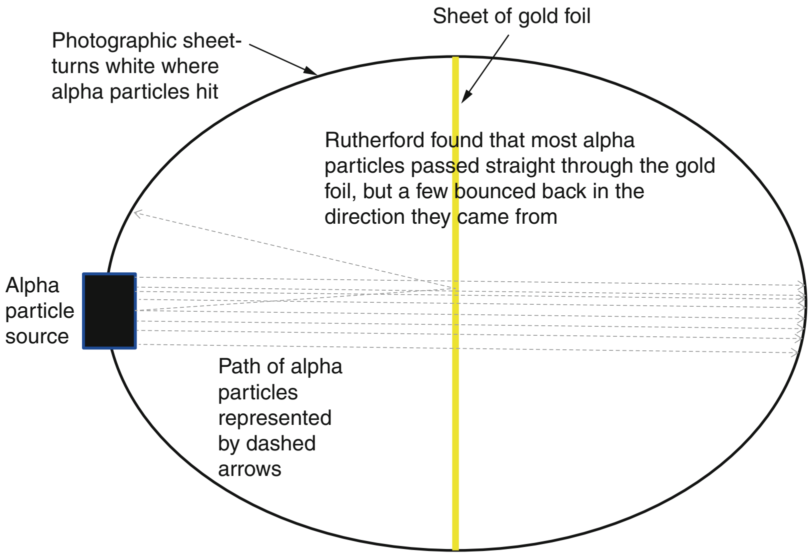
Designing and Assessing Scientific Modeling Tasks, Table 1 Defining performance expectation for modeling

Scientific practice: developing and using models	Disciplinary core idea: “Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons” (NRC 2012, p. 107)	Relevant phenomena: Rutherford observed that when alpha particles were shot at a thin sheet of gold foil, most of the particles passed through mostly unaffected, but a few returned close to the direction from which they came	Performance expectation: Develop a scientific model for atomic structure that can account for experimental results related to the structure of the atom

Note that the assessment task requires that students explain in writing how their model is related to the phenomenon; a diagram alone cannot fully assess all key elements of a model and if students demonstrate understanding of the performance expectation.

Assessing Student Responses

Base Modeling Rubric: A base, modeling rubric provides a general rubric for evaluating scientific models that explain a variety of phenomena. The base rubric includes the three elements of a scientific model and provides guidance about assessing different levels of student achievement



Draw (or revise) your model of atomic structure	How does this model explain Rutherford’s observations?

Designing and Assessing Scientific Modeling Tasks, Fig. 1 An assessment task. When Rutherford shot positively charged alpha particles at a thin sheet of gold atoms, he observed that most of the particles passed straight through but was surprised to see some that returned to the direction they came from

Designing and Assessing Scientific Modeling Tasks, Table 2 Base rubric for assessing scientific models

	Levels		
Criteria	0	1	2
Components: Model includes identification and specification of appropriate and necessary components, including both visible and invisible	Diagram shows an image of the phenomenon	Model may include both visible and invisible components, but may be missing key components, or components are not clearly labeled leaving uncertainty in the interpretation of the model	Model highlights all necessary components, including both visible and invisible, that are needed for explaining the phenomena. All components are clearly labeled or identified in description
Relationships: Model includes representations or descriptions indicating how various components within the model are related and interact with each other	Model does not indicate relationships or interactions between components of the model	Model is either missing key relationships or includes some inaccurate relationships between component	Model includes all appropriate relationships necessary for the explanation of the phenomena
The collection of relationships provides a causal account of the phenomena: The model is used to explain or predict phenomena or specific aspects of phenomena	Model is not used to explain phenomena	Model is used to try to explain phenomena, but there are some inaccuracies in the explanation of the phenomena	Model is consistent with available evidence and is used to explain phenomena

for each of the elements. Table 2 provides a general base rubric for assessing students' scientific models.

Developing Specific Rubrics: A specific rubric combines both the general structure of scientific models with the appropriate science ideas and evidence with a particular assessment task. Adapting a base rubric to develop a specific rubric involves aligning the rubric to a particular assessment task. The specific rubric includes determining what would count as appropriate components and relationships in the specific task. To develop specific rubrics, begin by using the base rubric and constructing the ideal student response for each element (Modified from McNeill and Krajcik 2008).

To develop the specific rubric for the Rutherford task, the specific components, relationships, and the connection to the phenomenon need to be identified. Note that these specifics are being defined with respect to the instructional methods used to cover the material in class. In this example, the students learned about Rutherford's gold foil experiment using a simulation where students manipulated the concentration of the positive charges and observed the effect on the electric field and motion of the positive alpha particles. This simulation can be found at http://concord.org/tst/rutherford-model.

Step 1: Identify the object/components: what components need to be specified. The key components needed to explain the results of the Rutherford observations include protons and alpha particles. Additionally, it is necessary to include that these particles are all positively charged. Further, the strength of the electric field around the protons is an important invisible component for explaining how the path of a few of the alpha particles changed so drastically.

Step 2: Specify the specific relationships: what relationships need to be specified. In the Rutherford example, there are two important relationships to include. Since the alpha particles and protons are all positively charged, these particles will repel. An additional relationship that is relevant for explaining Rutherford's observations is the connection between the strength of an electric field and the concentration of charged particles. The electric field is stronger around concentrated charges.

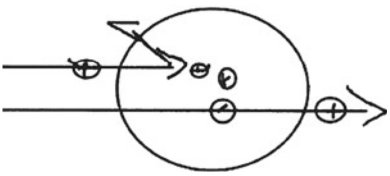
Step 3: Show the connections among the relationships. Do the connections among the

Designing and Assessing Scientific Modeling Tasks, Table 3 Specific rubric for assessing Rutherford modeling task

	Levels		
Criteria	0	1	2
Components: Model includes identification and specification of appropriate and necessary components, including both visible and invisible	Diagram shows an image representing the outcome of Rutherford's gold foil experiment	Model may include both visible and invisible components, but may be missing key components, or components are not clearly labeled leaving uncertainty in the interpretation of the model. Model may not indicate the charge of particles	Model highlights protons and alpha particles and identifies these particles as positively charged
Relationships: Model includes representations or descriptions indicating how various components within the model are related and interact with each other	Model does not indicate relationships or interactions between components of the model	Model is either missing key relationships or includes some inaccurate relationships between component	Model includes repulsive forces between positively charged alpha particles and protons. Model includes relationship between concentration of protons and strength of electric field
The collection of relationships provides a causal account of the phenomena: Model is used to explain or predict a phenomenon or specific aspects of a phenomenon	Model is not used to explain phenomena	Model is used to try to explain phenomena, but there are some inaccuracies in the explanation of the phenomena	Model is consistent with and used to explain the evidence from Rutherford's experiment that most of the alpha particles pass straight through the gold foil but a few are deflected at a large angle

Atomic model to explain Rutherford's observations from the gold foil experiment

Student's representation



Transcript from interview:
This is like the atom and inside of it is both the positive and the-protons and electrons, and when you send out, [an alpha particle] um one woulde either bounce off or go right through depending on what its charge was.
If the alpha particle hits a proton, it will be reflected because they repel; if it hits an electron, it would come right straight through

Designing and Assessing Scientific Modeling Tasks, Fig. 2 Student atomic model to explain Rutherford's observations

relationships provide a causal account for why the phenomenon occurs? Rutherford observed that a few of the positively charged alpha particles returned almost in the direction they originally came from. In order to change the path of the alpha particle this drastically, there must be regions with highly concentrated positive charges. However, the majority of the alpha particles passed almost unaffected through the gold foil. Thus, inside the gold atoms, there must be regions with highly concentrated protons and large regions without protons.

Adding these specifications to the base rubric shown in Table 2 develops the specific rubric. Table 3 displays an example of a specific rubric that would be used to assess students' responses to the task described in Fig. 1.

Example of Assessing Student's Model: Figure 2 provides an example of a student's representation of atomic structure and her

Designing and Assessing Scientific Modeling Tasks, Table 4 Evaluation of sample student model

Criteria	Evaluation	Description
Components	Level 2	Student included protons and alpha particles. Though these are not explicitly labeled in the diagram, the student identified them in the description of the model during the interview. The protons and alpha particles are all labeled with plus signs indicating they are positively charged
Relationships	Level 1	Student included repulsive forces between the alpha particles and protons. However, the relationship between the concentration of positive protons and the strength of the electric field is missing. Instead, the student relates the path of the alpha particles to the interaction with individual particles rather than electric fields created by collection of particles
Connection to phenomenon	Level 2	The student used the model to explain how some alpha particles were reflected and others passed through. Though the student had an inaccuracy in that she related the path of the alpha particles to individual particles rather than a collection of particles, this inaccuracy was captured in the evaluation of the relationship category. The student's description of the phenomenon is accurate and the model provides a causal account to explain the phenomenon

description of how the model related to the phenomenon. The assessment task here is a bit different than the task described above. The students drew representations of atomic structures and then were interviewed about the representations and how they related to a variety of phenomena. The example is provided to illustrate the connection between the base rubric, specific rubric, and a specific example. The example includes the representation the student drew, a selection of the transcript from the interview, and an evaluation of the model using the rubric.

Overview of the analysis of the student model: The model includes appropriate components. Plus and minus signs indicate the charges of the various components. Arrows show a relationship between alpha particle and the path of the alpha particle depending if it interacts with a proton or not. However, the model includes inaccurate ideas: The student's model has alpha particles interacting with an individual proton or electron rather than with the strong electric field due to a concentration of multiple protons. Table 4 displays an evaluation of this student's model based on the criteria described in the base and specific rubrics.

Summary Statement

Scientific modeling engages learners in a complex and essential scientific practice. Teachers need to support students in developing and revising models. This includes providing a structure to develop and evaluate student's models. This structure also helps students to evaluate and revise their own models as they gather additional evidence. Due to the complex nature of the practice of scientific modeling, it is important to describe the three elements of the model to evaluate the components included in the model, relationships between these components, and the connection among the components and relationships in the model to give a causal account of why the phenomena occurs. Additionally, because models explain or predict phenomena, it is important to write assessment tasks that ask students to connect their models to phenomena. Rubrics can monitor students developing conceptual understanding as students continue to build and refine their evolving models. The analyses of students' models provide insights into students' integrated conceptual understanding.

Cross-References

- ▶ Argumentation Environments
- ▶ Assessment of Knowing and Doing Science
- ▶ Formative Assessment
- ▶ Inquiry, Assessment of the Ability to
- ▶ Summative Assessment

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Developmental Perspectives on Learning

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Human curiosity to understand the immediate world and wider universe we inhabit generates a legacy of cultural capital for succeeding generations. Cumulative as well as revolutionary insights spawn a body of knowledge in the form of artifacts, information and communication formats, and centers of research populated by living human expertise. Into this context arrive about 250 births per minute across the world. What do we know about the induction of these new arrivals to the frameworks science offers for making sense of the world? How and where should we begin the enterprise to shape the unknowing dependence of neonates toward scientific literacy for all and a more single-minded commitment for some?

The scientific study of intellectual growth from infancy to maturity is a relatively recent discipline, propelled in the early twentieth century by major contributions from Piaget and Inhelder in Geneva and Luria, Vygotsky, and their circle in the Soviet Union. While the former focused on the developmental construction of knowledge (genetic epistemology) as a "natural" process of intellectual adaptation, independent of instruction, the latter prioritized sociohistorical enculturation processes, especially as mediated by language, with teaching and learning a preeminent interest. Vygotsky's introduction of the term "zone of proximal development" (readiness for the next jump in learning) into educational vocabulary remains important in considering progression.

A number of major disciplines inform thinking about progression in children's developing science-relevant capabilities: cognitive-developmental psychology and curriculum studies complement and supplement science knowledge. The trend in such research has been to extend inquiries to increasingly younger age groups (including pre-birth studies by psychologists) and, on the part of curriculum researchers, an interest in "emergent science" in children from about age three onward. Recent decades have also brought dramatic social contextual changes in the technologies of information and communications environments to which infants and young people in many societies are exposed. This social change is linked to a strong prevailing value position in liberal democracies, manifest in the promotion of attitudes and behaviors consistent with an expectation that, from a very early age, learners should show curiosity and be exploratory, autonomous seekers and evaluators of information. Notwithstanding the enormous body of existing scientific knowledge, active assembly of knowledge is valued by educators, rather than passive receipt of transmitted information. The implication is that a judicious ordering and scaffolding of the salient experiences to be negotiated by learners is essential to achieve a regulated, cumulative progression.

While a senior school and later adult science education specialism may apply to only a minority of students, the underpinning cognitive, affective, and social skills that comprise essential antecedent capabilities to a mature scientific literacy can be identified and nurtured from a very young age. Three aspects describe most of the important foundations for the development of scientific literacy: ideas together with the evidence to support them;

scientific inquiry skills (including variable handling), sometimes referred to as "procedural understanding"; and conceptual development, in the form of knowledge and understanding of the subject matter of science.

Progression with Ideas and Evidence

The area of ideas and evidence – that is, having ideas about what entities exist, how they might be classified, and how such beliefs are justified – has pervasive relevance across the curriculum and as a life skill but is quintessentially important to scientific thinking. While independence of thinking is valued in science, particular times and cultures frequently exert pressure to conform to prevailing beliefs, whether fueled by precedent, folk knowledge, superstition, or simply the weight of orthodoxy (as Galileo's experience confirms most dramatically).

Constructivist research conducted in recent decades confirms that children have ideas, but need an accepting ambience in which to express them. By engaging in a dialogic process, they may gain confidence and be empowered to take ownership of their learning. However, as well as overcoming reticence, the emergence of a "theory of mind" (ToM) is a developmentally significant process. Initially, it seems that young children assume just one reality, which is that which self-evidently exists in their own minds. What is known is assumed to be known by all. The dawning realization that others possess minds of their own opens the awareness that those others also have ideas, though initially in a restricted sense and with an important limitation: the alternative ideas that have come to be accepted are not treated as equally possible alternatives, but as absolutes ("right" or "wrong"), depending on whether they conform to the one known and absolute version of what is. The absolutist (Kuhn 2005) view that "the way things are" is shared by everyone has implications for the development of argumentation skills, because the possibility that others might hold "false beliefs" does not reach the agenda. With increasing experience and corresponding with children's maturation to early adolescence, the appreciation of others' ideas progresses to a "relativist" quality, when alternative beliefs are more readily accepted as genuine options. This tolerance of ambiguity, emerging during adolescence, can be bewildering and may lead many young people, males especially, to seek refuge in the imagined "certainties" of science. Resolution arrives with the development of a value system that allows claims, beliefs, or arguments to be weighed against warrants and evidence, where alternatives are reflected upon by reference to a system of judgment in an "evaluativist" mode. So it is that "argumentation" has become integral to some science education programs, though there is evidence that the evaluative quality of reasoning is not easily achieved. The appreciation that situations may lack sufficient evidence to inform a decision is challenging, and the absolutist and relativist qualities of performance are by no means absent in many forms of behavior in adult life.

The Development of Inquiry Skills

Progression in the manner in which evidence to support claims is gathered has been relatively well researched by science educators. Systematic empirical inquiry is a defining feature of scientific behavior, which in many curricula is prioritized over other considerations (such as science subject matter). Scientific inquiries can be deconstructed into subsets of process skills that contribute to evidence-collecting and hypothesis-testing procedures in which learners gain increasing autonomy and control. These skills (usually encompassing hypothesizing, controlling variables, observing and measuring, collecting data, and interpreting or evaluating results) are called upon in planning and conducting investigations. Each skill is to some degree subject to its own developmental trajectory. For example, hypothesizing can be thought of as the expression of an idea in a form that may be tested empirically, so is dependent on the developments described above in the domain of ideas and evidence. Formally considered, an investigation should assume a null hypothesis, that is, that the outcome of any treatment or independent variable has no effect, but younger learners may seek to conduct an experiment that “proves” their idea.

Observation, quantification, measurement, and the defining of variables develop in a closely related manner. Accurate observation can be encouraged to develop, with stereotypes and theory-laden perception brought to metacognitive awareness and displaced by accurate recording. Children in their early years will be able to handle nominal (categorical) variables, defined by simple observable attributes such as color and shape, moving to ordinal variables defined by relative magnitude; gradually quantification is introduced, allowing interval variables to be handled. This increasing complexity will, in time, be applied to the coordination of both the dependent and independent variables.

Quantification tends to proceed from nonstandard (handspans, arm spans, footsteps, etc.) to standard metrics, starting with the familiar human scale of experience before moving to macroscopic and microscopic scales that require measuring devices. Over time, measurement reliability and precision increase, as well as the complexity of the units used. For example, distance and time are simpler for learners to handle than the relational concept of speed. The recording of outcomes may start with pictograms, moving to tables, bar charts, and line graphs. Causal relationships are observed and described in everyday events from an early age, so that with experience, learners begin to operate the distinction between the independent variable (the cause, such as angle of the sun in the sky) and the dependent variable (the effect, such as shadow length).

Younger children are encouraged to begin their inquiries using “fair testing,” where the teacher encourages consideration of the factors that might influence the outcome in an investigation. This level of development is often characterized by children’s desire to “control everything,” even down to consistency in the clothes they wear. Identification of valid control variables requires a greater understanding of the conceptual system under consideration than is likely to be available to younger children.

Progression in Conceptual Understanding

For science educators, the end of the twentieth and beginning of the twenty-first century was a time of enormous interest and research activity into learners’ conceptual understanding. Piaget’s structuralist epistemology was being increasingly questioned, though stage-developmental interpretations of progression continue to have significant support. By contrast, the Genevan nondirective clinical interview technique, together with classroom variations that have in common the resolve to heed carefully learners’ ideas, to take them seriously as indicators for intervention, is an enduring legacy. This tranche of inquiry shares a concern to understand the ideas pupils bring with them to their science lessons, prior to formal instruction. As a brief example, the evaporation of water from puddles and from washing on the line is an everyday phenomenon experienced by children prior to any formal instruction. Children will make their own sense of these events and we should make no assumptions of a unifying causal mechanism being understood to explain the shift from wet to dry. For children lacking any concept of object permanence, the water in the puddle may be believed to have “disappeared,” its shift to a state of nonexistence being unproblematic. In other contexts, it may be asserted that the water has “soaked in” or traveled to the source of the heat (the sun or a hot radiator) that caused it to move. (Look inside the hot radiator and you will find the missing water.) With experience, conversations, and exposure to secondary sources of information, the macroscopic appreciation of water as existing in three states will be grasped. With formal instruction, a microscopic model that makes sense of matter as particulate will be introduced, though with the salutary reminder for teachers that the model may be filtered or distorted by earlier understandings. With awareness of such possible conceptual milestones, teachers can apply not just science subject matter knowledge but pedagogical content knowledge (PCK) to their instructional strategies.

In the last 30 years, constructivist research has gripped science educators’ imagination for its relevance to daily classroom experience. One outcome is a bibliography of over 8,000 entries compiled at the IPN (Leibniz Institute for Science and Mathematics Education at the University of Kiel) that documents research on teaching and learning science from constructivist perspectives, theoretical and empirical, from leading journals and publications in English and German, covering the period from the late 1970s to 2009, by which time Internet search functionality was felt to have made continuation of the compilation redundant. The research, however, continues, and in a sense will always need to be updated, so long as the broader science endeavor continues with new insights and discoveries, while curricula adapt to changes in priorities and in understanding. The ambitious AAAS Project 2061 (AAAS 2007) is one example of an ongoing program (the start and end marked by the 75 year cycle of the Halley comet's visibility from the Earth) that intends to improve education for 4–19-year-olds by detailing such developmental links and trajectories in the growth of understanding.

The "nature or nurture" debate that preoccupied discussion of development during the first half of the twentieth century, together with questions as to whether intelligence should be construed as global in nature or comprising a range of "factors," has been the subject of a more nuanced form of research benefiting from the tools of neuroscience. Neuroconstructivists suggest multiple and interacting causation and epigenetic plasticity in the functioning of the brain. The digital impact on child development erodes the status of "pre-instruction," yet environmental influences such as social class must be acknowledged as background variables that have a significant impact on progress in learning of individuals and groups. Attempts to uncover, describe, or manage continuity and progression in science learning trajectories must be mindful of the turbulence attributable to such factors, which might help to explain the absence to date of conclusive contributions from the small number of longitudinal studies conducted. An apposite metaphor is that we are more likely to discern "migration routes" than very clearly defined corridors or trajectories. Nonetheless, the case for an evidence-based ordering of curriculum experiences that aim to support continuity and progression and which informs the formative assessment that supports effective teaching and learning is increasingly accepted as indispensible.

Cross-References

- ▶ Conceptual Change in Learning
- ▶ Constructivism
- ▶ Learning Progressions
- ▶ Piagetian Theory
- ▶ Socio-Cultural Perspectives on Learning Science

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Developmental Research

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Introduction

Developmental research is a particular way of addressing the basic questions of why and how to teach what to whom. It involves a cyclical process of small-scale in-depth development and evaluation, at a content-specific level, of exemplary teaching-learning sequences. It aims to produce an empirically supported justification of the inner workings of such a sequence, which is claimed to be an important contribution to the expertise of teachers, curriculum developers, and educational researchers.

The Inner Workings of a Teaching-Learning Sequence

Two related elements are involved in the intended justification of a teaching-learning sequence about some topic. First, a detailed description of the desired (by the researcher) development in what students believe, intend to achieve, are pleased about, and so on, in relation to the topical contents. Second, a detailed explanation of why students' beliefs, intentions, emotions, etc., can be expected to develop as described, given such and such learning tasks and when guided by the teacher in this and that way. In this explanation the developmental researcher can rely on what may be called commonsense psychology, i.e., what everybody uses all the time to find out about and influence the mental life of others.

Developmental research tries to improve on the practical wisdom of experienced teachers, both in being more detailed and specific with respect to expectations beforehand and in being more systematic and impartial in evaluating whether or not the expectations have come true. Developmental research also aims at more than what can be achieved by a pretest-posttest research design. Such a design may give an indication *that* a teaching-learning sequence works or fails to work: are the intended learning goals reached, as measured by the progress from pretest to posttest? Developmental research also aims to understand in detail *how* and *why* the teaching-learning sequence works or fails to work: does the teaching-learning process itself proceed as hypothesized? It is precisely this detailed content-specific understanding of the process that promises to offer a worthwhile, evidence-based resource to guide professional practice.

Value-Laden Choices

Separate from the question why a teaching-learning process can be expected to proceed as desired, there is the question of why in the first place it is desirable that there is a teaching-learning process that proceeds in this particular way. Here values necessarily enter the picture. Since the outcomes of developmental research can only be properly communicated and discussed if placed within and judged from the value-laden context in which they are obtained, the developmental researcher will at least have to make explicit his value-laden choices. In particular the choices concern the goals he wants pupils to reach and the tenets or principles underlying the ways in which he wants to make pupils reach the goals (such as that students should be actively involved or that they should know all along what they are doing and why). The goals and principles together set the quality standard against which the developmental researcher himself wishes his outcomes to be measured.

From the value-laden character of learning goals and educational principles, it does not follow that they can be chosen freely. The learning goals cannot simply be decided on in advance. Whether they can be realized with sufficient quality, as measured by the developmental researcher's own principles, will have to be investigated. The connection between the educational principles and empirical investigation is much less stringent, and typically the developmental researcher tends to hang on to his principles. But if again and again he fails to meet the quality standard set by his principles, he may eventually begin to question the principles themselves or the theory from which they were derived.

The Heart of Developmental Research

Whereas commonsense psychology serves to explain why a teaching-learning process can be expected to proceed as desired, there is no theory that serves to actually design the teaching-learning process itself. The developmental researcher will benefit from a deep insight into science, its relations to technology and society, its philosophical foundations and its historical origins, and he may well be inspired by one or another psychological or learning theory. From all of this he may even have derived the goals and educational principles that set the quality standard which the teaching-learning activities he is to generate in the particular case at hand should meet. This standard may function as a checklist, make the developmental researcher receptive to useful ideas, and make him recognize a good idea as such. But the quality standard plays no further facilitating role in actually generating particular teaching-learning activities. The generation of a particular teaching-learning process is an activity sui generis and the very essence of developmental research. In the literature it is variously described as a process in which one's goals and educational principles are applied, implemented, translated, transposed, embodied, given content, or operationalized. But despite all these characterizations, it is a process that refuses to be regularized. Just like any creative process, it is a matter of finding local solutions to local problems. It depends on skill, sweat, talent, persistence, and a good deal of luck. Success or failure may critically depend on details such as the actual wording of tasks.

Vital Methodological Components

One vital methodological component of developmental research concerns the construction of a so-called *scenario* or *hypothetical teaching-learning trajectory*. This consists of the value-laden choices (see section "Value-Laden Choices" above) and the justification of the teaching-learning sequence (see section "The Inner Workings of a Teaching-Learning Sequence"). Simply making explicit the reasons for one's expectations about how the teaching-learning process will proceed may in itself already be sufficient to bring to light quite a lot of wishful thinking. Triangulation in the form of discussing one's scenario with colleagues will make the expectations more realistic by diminishing cases of tunnel vision.

A second vital methodological component is to put the design to the test. This involves the use of the scenario as a theoretical prediction of what will happen. The test then provides the evidence in light of which the scenario is to be evaluated. The comparison of the prediction to what actually happens is not straightforward. What actually happens will have to be interpreted in terms of what, at various stages of the process, students believe, mean by what they say, intend to achieve with what they do, and so on. Here too triangulation, in the sense of coordinating the interpretations of various researchers, is a good methodological advice, if only to avert the danger of seeing what one hopes to see (one's predictions). Proceeding in this way, and relying on commonsense psychology, the researcher can make his interpretation as rigorous, systematic, and objective as can be.

A third vital methodological component consists in reflection on the test, in order to improve the scenario in the face of all the points where the expectations did not come out. In some cases it may be possible to "explain away" a deviation. This may happen if the teacher did not guide the activity as intended, while there are indications that students would after all have done what they were expected to do if the activity had been guided as intended. More frequently the deviations reflect a clear need to make adjustments, though typically it will not be so clear which adjustments will suffice. Since a scenario is a highly interrelated complex, a failure that clearly emerges in one area may just be a symptom of a problem elsewhere. Another aspect of the interrelatedness is that necessary changes in one area are likely to require changes in several other areas. Some further, and deeper, complexity may arise if one decides not to make adjustments to the design in order to better realize the process that one wanted, but instead to make adjustments to what one wants the process to be like. That is, one may feel a need to adjust one's educational principles or learning goals.

Nature and Use of Outcomes

The aim of improving a scenario cannot be to eventually arrive at "the ultimate" scenario – one whose predictions will come out in exactly the predicted way. All that matters is that a scenario can be judged *good enough* to serve as a valuable guideline for understanding and guiding what goes on in actual classrooms. In each actual case the teaching-learning process will without doubt meander in a somewhat different way around the main predicted path. Several revisions are typically needed before one is even willing to consider the question whether or not a scenario can be judged good enough, and the first revisions are likely to require considerable adjustments. But no matter in how many classes or with how many teachers one has tried a scenario, the claim that it is good enough will always be of the following kind. If handled with proper care, the teaching-learning process will proceed more or less as intended, under normal circumstances. Despite the inherently vague nature of such claims, they are worthwhile, evidence-based contributions to the expertise of teachers, curriculum developers, and educational researchers.

The explicit specification of the value-laden choices and the detailed account of the envisioned teaching-learning process allow a teacher to get a feel of how the process appeals to him. In combination with the empirical support, the teacher can form a judgment as to whether or not he can see it work in his circumstances or see himself able to adapt it to his specific circumstances. In this sense a good enough scenario allows a teacher to reach an informed decision about whether or not to make an effort to use it.

Developmental research aims to engender progress in science education research in at least three ways. First, within the quality standard set by a given matrix of learning goals and educational principles, one good enough scenario may arguably better meet the standard than another one. Second, within the quality standard set by fixed educational principles, for a growing number and variety of topics (with associated learning goals), one may be able to produce good enough scenarios. Third, researchers operating with different quality standards can critically discuss the ways in which their respective theoretical perspectives have differently shaped the concrete activities in their respective teaching-learning sequences. At least this may lead to clarification of the educational principles or theoretical perspectives at stake and perhaps even to argumentation about which ones are better. Above all such an exchange will keep theoretical considerations firmly secured to what they are supposed to be relevant for: concrete teaching-learning activities. This is progress too, when compared to the abstract and freewheeling manner in which theoretical frameworks are frequently discussed in the literature.

The developmental researcher does not expect progress in the form of some general body of knowledge by virtue of which curriculum development will be made easier or more efficient. In this respect developmental research may differ from design-based research, in which design principles are often supposed to play such a facilitating or enabling role. It is rather by being exposed to a lot of scenarios, and to empirical tests and critical peer discussions of the scenarios, that curriculum developers are expected to benefit from developmental research.

Drawbacks and Boundaries

There are important educational issues that typically fall outside the scope of developmental research, such as the following: How can one make the value-laden choices of the developmental researcher a major concern of many teachers? What are useful techniques for teachers to make an envisioned teaching-learning process happen in their classrooms? What about large-scale implementation or dissemination?

Developmental research does not sit easy with the current emphasis on quantity of “output.” It takes quite a lot of effort and time to produce a good enough scenario, and because of the formidable complexity of a scenario, it is hard to report concisely its justification and its test. This puts serious pressure on the progress that developmental research aims to engender in what it considers to be the core business of science education research: to construct, critically discuss, and empirically evaluate detailed content-specific justifications of teaching-learning sequences.

Cross-References

- ▶ Learning Progressions
- ▶ Model of Educational Reconstruction
- ▶ Teaching and Learning Sequences

Further Reading

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Dewey and the Learning of Science

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The connection between John Dewey and science education is enduring, vast, and varied. It would not be much of an exaggeration to say that Dewey had an influence on nearly all aspects of science education. Nevertheless, three influences stand out. First, Dewey proposed that the mind evolved in response to problem-solving situations and, consequently, the mind functions best in practical, problem-solving situations (e.g., Dewey 1916). According to this theory, learning is most effective when undertaking in the context of problem-solving and real-world situations. Second, similar to William James (1890), Dewey (e.g., 1938) firmly believed in the continuity of experience, where past, current, and future experiences were inextricably linked. This view foreshadowed modern constructivism including such principles are the importance of real-world experience and the role of prior knowledge in learning. Third, Dewey (1913) proposed that interest is a necessary component of learning. Interest activates a process of meaningful learning culminating in understanding instead of rote learning. Interest develops from connecting learning to prior experience, and it motivates the application of learning in everyday experience. These three ideas were foundational to the progressive era of education, which DeBoer (1991) identified as spanning 1917–1957. Within the field of science education, progressivism was characterized by dissatisfaction with educational practices that were too teacher centered and with content too far removed from real-world problems and students' prior experiences (DeBoer 1991). Progressive science education sought to contextualize learning in meaningful problems, involve students in experiential learning, and connect science to students' prior experience and interests. These progressivist goals have persisted in science education and are prominent in the twenty-first-century movements emphasizing such things as inquiry or problem-based learning and culturally relevant pedagogy.

Charting Dewey's Influence: Scholarship in Science Education Journals (1992–2012)

Dewey's influence continues to expand. One way of describing the nature and strength of the connection between science education and the work of John Dewey is to examine how his work has been cited in science education journals. We examined the past 20 years of four prominent science education research journals: the *Journal of Research in Science Teaching*, *Science & Education*, *Science Education*, and the *International Journal of Science Education*. We recorded all substantive connections to John Dewey making note of the author and date and, most importantly, assigned a keyword describing the substance of the connection to Dewey. The list below is ordered according to the number of articles making substantive connections to Dewey's work.

Inquiry

Contemporary work by science educators clearly suggests they view inquiry as a distinctive quality of Dewey's work. Indeed, the works of Dewey frequently read by educators – "How we Think" (1933), "Experience and Education" (1938), and "The Child and the Curriculum" (1902), for example – all highlight intelligent activity as a pragmatic process of encountering problems, testing hypotheses, actively engaging with the problem situation, and reflecting on consequences. Science educators focused on inquiry have cited Dewey's work in both philosophical examinations of the nature of inquiry and practical examinations of learning activities and teaching practices.

Pragmatism and Epistemology

Dewey's view of the nature of knowledge and the means by which something becomes knowledge is associated with the philosophical school of pragmatism. In brief, pragmatism holds that the value of a theory or belief lies primarily in its consequences, specifically the success and value of its practical application (Dewey 1929). Areas of science education influenced by Dewey's epistemology and pragmatism include the proper interpretation of Dewey's philosophical views, the nature of science, and the practical implications of teaching science.

Reform

Many of Dewey's works highlight how inquiry – knowing and doing inextricably connected – is central in the proper quest for greater certainty (Dewey 1929). In establishing his view of inquiry and knowledge, Dewey frequently criticized long standing dualisms – such as the separation of mind and body, theory and practice, and reason and experience, to name a few – as artificial and hindering the productive philosophical discourse. Science education reformers have resonated with Dewey's spirit of open-minded liberalism and progressivism, especially his willingness to dissolve categorical boundaries and bring together traditions that have long stood in opposition (Dewey 1902, 1938). Dewey's work has been cited in discussions about the proper role of science education, the importance of authentic inquiry activity, and the vital role of democratic, inclusive processes in science education.

Experiential and Hands-On Learning

Dewey's theory of experience, particularly as articulated in *Experience and Education* (1938) and *Democracy and Education* (1916), states that knowledge comes from experiences with the real world, prior experiences form the basis of new learning experiences, and new learning experiences have the purpose of transforming future experiences in the world. Further, educative experiences involve both an active trying out element (e.g., experimenting) and a passive undergoing element (i.e., experiencing the consequences and developing meaning from them). Science educators have drawn on this theory of experience to advocate the use of direct experience with real-world objects, events, and situations. They have also drawn on this theory to describe the nature of science learning experiences and consider the qualities that make for effective learning experiences (e.g., need for reflection and theory building to accompany hands-on activity).

Aesthetic and Transformative Experience

Dewey's theory of aesthetic experience as best expressed in *Art as Experience* (1934) articulates processes involved in undergoing aesthetic experiences and identifies a particularly meaningful and transformative type of experience, which Dewey termed "an" experience (Jackson 1998). Science educators have drawn on Dewey's theory to identify aesthetic characteristics (e.g., anticipation building toward consummation) and transformative qualities of science learning. Regarding the latter, particular emphasis has been placed on how science concepts (like art) can enrich and expand everyday experience by transforming perceptions of the world. This work also draws on Dewey's construct of an idea from *How We Think* (1933). Models of science instruction focused on fostering aesthetic and transformative experiences have been developed from Dewey's work.

Dewey and the Learning of Science, Table 1 References to Dewey in Science Education Journals[a]

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(*continued*)

Dewey and the Learning of Science, Table 1 (continued)

Topic	Citation
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Dewey and the Learning of Science, Table 1 (continued)

Topic	Citation
Other	***Reflection***
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[a] We examined the past 20 years of four prominent science education research journals: the *Journal of Research in Science Teaching*, *Science & Education*, *Science Education*, and the *International Journal of Science Education*. We list only articles judged to make substantive connections to John Dewey's work

Aspects of Dewey's Work Not Prominent in Science Education Journals

In addition to identifying the more common connections science educators have made to Dewey's work in the past 20 years, our review of four major science education journals also reveals aspects of Dewey's work that, perhaps surprisingly, have not received much attention.

The Importance of Subject Matter

In 1902, Dewey wrote "*The Child and the Curriculum*" to address what he perceived to be serious misinterpretations of his earlier works. Dewey felt that educators had taken his recommendations for child-centered education too far and, as a result, educators had neglected the importance of both the subject matter and the teacher. Dewey disagreed that educators must choose between child-centered or curriculum-centered approaches and, instead, argued that such an either/or dichotomy was false and unproductive. Dewey offered an analogy of an explorer (child) using a map (subject-matter idea) to illustrate how intelligent, thoughtful learning required both an active learner and the disciplinary structure of a subject area. The role of the teacher was to facilitate the having of educative experiences by the inquiring student (explorer) with the subject-matter ideas created by disciplinary experts (map). This central role of curricular ideas as well as the teachers' vital role in mediating between the child and curriculum – "psychologizing the subject matter" – received considerable attention in the 1980 and 1990s, largely in connection to Shulman's (1986) construct of pedagogical content knowledge. However, substantial connections in this aspect of Dewey's work seem to be relatively rare in science education research in the past 20 years (Avraamidou and Zembal-Saul (2005) is an exception).

Learning as Social and Cultural

Another important legacy of Dewey's work is an understanding of learning as a social and cultural process. Along with George Mead, Dewey developed a theory of the social origin of mind. He described learning as a process of meaning making through social interaction. This aspect of Dewey's work shares an epistemological foundation with sociocultural perspectives on science education (Lemke 2001). In addition, many of Dewey's writings on pedagogy emphasize democratic forms of education (see, e.g., *Democracy and Education*). Dewey particularly emphasized pluralistic participation believing that schools should give a voice to all and provide a means for even the disadvantaged to shape society. This focus of Dewey's educational philosophy foreshadowed current science education perspectives falling under a critical theory umbrella (e.g., Calabrese Barton 2003). Thus, it is surprising that few references to these aspects of Dewey's work are found in prominent science education journals over the last 20 years (Table 1).

Cross-References

- ▶ Conceptual Change in Learning
- ▶ Constructivism
- ▶ Ecojustice Pedagogy
- ▶ Epistemic Goals
- ▶ Inquiry, as a Curriculum Strand
- ▶ Interests in Science
- ▶ Socio-Cultural Perspectives on Learning Science

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Dialogic Teaching and Learning

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Introduction

There is an increasing interest in studies of classroom discourse to inform and analyze the process of teaching and learning science. The reason for that is a theoretical assumption that there is an intrinsic relationship between language and thinking. According to the sociocultural approach inspired by Vygotsky, humans learn by the mediation of signs. According to Bakhtin, language is a system of signs that allows us to share a sense of the world with others, and this process is achieved by joint participation on particular social activities. Thus, language is not a simple way of communicating to others but a means to create and share a sense of the world, a powerful system that allows us to think together. Besides, learning science implies learning the languages of science, which codes a specific worldview, related to the social practices of science in society.

This explains the interest of science education researchers in contributing to the mastering of discursive practices, which allows teachers and students to seek a common knowledge based on scientific concepts. Instead of just claiming that language is a powerful mediational tool, this research agenda seeks to understand which kind of classroom discourse favors the progressive appropriation by the students of scientific concepts and the understanding of science as a cultural enterprise of producing and validating knowledge.

Dialogue is an important aspect of language itself. Based on the Bakhtin work, Wells (2007) suggests that dialogue is the most powerful mediational tool used by children and adults to negotiate meanings in activity. According to this perspective, dialogue is a two-way bridge of sign-based activity that makes it possible for a person to enter into the system of shared meanings in a society. Through dialogue, the child (or adult) can construct her "meaning potential" and thus convert in her own words the words of others, according to her feelings, intentions, and personal understanding of the social and material world. Another reason for the importance of dialogue in science education research agenda is that it allows addressing the problem of how the students' existing informal ideas interact with the new scientific knowledge introduced in the classrooms.

Researchers in education, including in science education, have identified a variety of patterns of classroom talk. The most prevalent pattern of science classroom interactions is a triadic "dialogue" in the form of "initiation-response-evaluation" (or I-R-E) or "initiation-response-feedback" (I-R-F) structures (Mortimer and Scott 2003). These patterns are commonly identified as authoritative (or non-dialogic) as they are centered in the teacher's initiative and power, and it is the teacher who controls the agenda and the contents of talk.

Despite of the effort of many curricular reforms and teaching guidelines, dialogic discourse is still unusual in science classrooms. Results from a range of countries show that even teachers involved with innovative teaching projects (inquiry-based, problem-based, project-based, argumentative teaching sequences, among others) and from a range of school levels (from primary to undergraduate courses) adopt mainly triadic interactions in whole-class discussions. These paradoxical results reinforce the need to review the notion of dialogic teaching (Scott et al. 2006; Littleton and Howe 2010).

Moreover, it is necessary to distinguish teaching science from learning science. The presence of dialogue in the learning practices of the students in a particular subject does not always match the way in which the subject was taught. After all, teaching practices create opportunities for learning but do not determine what and how the students will learn. Thus, to address the topic "dialogic teaching and learning," I start by discussing dialogue in science learning and then exam affordances and constraints of dialogue in science teaching.

Learning as Putting Science into Dialogue

I adopt here a sociocultural approach that conceives learning science as a result of enculturation process. According to this perspective, in school science classes, students are being introduced to the ideas and practices of science and are making these ideas and practices meaningful in a personal perspective.

Learning science is an intrinsically dialogic activity. Meaning making is an interpretative and, thus, a creative activity; faced with new science ideas, each student must create his/her own models to relate these new ideas and tools provided by the teachers to his previous ideas and ways of knowing. For that, she must put the scientific ideas into dialogue to other types of knowledge and, particularly and because of the informal ideas she brings to the class, with the epistemology of everyday life. The world of science being taught often differs deeply from the students' perceived natural world, constructed by direct experience in everyday life.

Following Bakhtin and his circle, dialogism is a feature of human understanding of the world. According to him, any utterance is a link in a chain of human communication. Every utterance is a response to previous ones and seeks an answer to them. It means that there is neither a first nor a final word about any issue. Based on a conception of discourse as language in use in social life, Bakhtin states that any understanding must involve an active response to the words of others.

In the actual life of speech, every concrete act of understanding is active: it assimilates the word to be understood into its own conceptual system filled with specific objects and emotional expressions and is indissolubly merged with the response, with a motivated agreement or disagreement. To some extent, primacy belongs to the response, as the activating principle: it creates the ground for understanding. Understanding and response are dialectically merged and mutually condition each other; one is impossible without the other (Bakhtin 1981, p. 282).

The Bakhtinian concept of responsivity is related to a dialogic stance; this is conceived as a relationship in which the interlocutors perceive themselves to stand with respect to their addresses. The concept of responsivity also helps to conceive dialogic teaching as a cohesive and temporal organization of the students' educational experience, in order to enhance progressive development of their understanding.

What Counts as Dialogue in the Science Classroom?

Below I present four different ways of conceiving of the ideas of dialogism in school science. The first meaning is very popular among teachers and sees dialogue as just teacher talk with the participation of students. However, this is not dialogic in the manner in which Bakhtin conceived it; dialogic relationships do not coincide with conversation replies. Educational research demonstrates that most "dialogues" in [science] classrooms are just recitation scripts in which the students try to complete the desirable answer from the teacher. However, in some cases the teacher does address different points of views and reviews arguments from both sides to compare and contrast perspectives.

A second perspective about dialogic teaching is based on the Bakhtinian distinction between two different forms of discourse, one more open to divergent ideas – what Bakhtin (1986) called "internally persuasive discourse" – and the other more closed, expressing a single perspective and demanding its full acceptance, namely, "authoritative discourse." Based on this distinction, Mortimer and Scott (2003) suggest that the basic feature of dialogic discourse in science classrooms is the consideration of students' points of view, besides the scientific perspective.

Dialogic discourse means, according to this approach, the encounter of different voices. Talk is considered to be more dialogic the more it represents the students' points of view, and the discussion includes both their and the teacher's ideas. This is in contrast with authoritative discourses where just one point of view, the school science perspective, is taken into account. According to the Mortimer and Scott, the consideration of different points of view in the science classrooms is fundamental for making connections between scientific and everyday ways of thinking and talking. The scientific perspective is considered as a social construction among others (religious, esthetical, philosophical, practical constructions), but a powerful one that has some specificity that must be acknowledged and experienced by the students.

The third approach to address the problem of dialogic teaching also comes from the philosophy of language of Mikhail Bakhtin. Contrary to the second approach (above), here dialogism is considered as a general notion of language, not as a particular kind of talk. Whatever kind of talk is being conducted in social life, every utterance is addressed to a listener and seeks to impact on that listener's understanding. One can say that, whatever kind of discourse is used in the classroom, dialogism will be always present, as the students use their counterwords to understand the scientific ideas introduced by the teacher. However, while this idea is very important, it is more closely related to leaning than to teaching; this third approach to dialogic teaching does not help to conceive which kind of discourse would provide best opportunities for learning.

The fourth approach to dialogic discourse emphasizes the distribution of power and control between teacher and students in conducting classroom discussions. From this perspective, attention is to be put on the interactive patterns of discourse, ranging from triadic moves (IRE or IRF) to open discussions. In IRE patterns, the student's participation is limited to giving brief responses to the teacher's questions, searching for the "right answer." However, triadic patterns are not always closed to students' views, as the third move from the teacher may involve not just evaluative statements but encouraging feedback, supporting students' participation (Wells 2007). Even then, the teacher is still in complete control of the discourse. This means that teacher's control may be not the main issue to be considered to address dialogic discourse in classroom settings. In some cases, whereas classroom interactions can be ideologically dialogic, in terms of considering multiple ideas and voices, it can be discursively non-dialogic, in terms of teacher control. So, it is important to note dialogic stances, which involve power and positioning from both students and teachers.

Considering such debate I reinforce the presence of multiple points of view as the main issue concerned with dialogic classroom discourse. However, such discourse may occur in a variety of forms, depending on:

1. Discourse participants (teacher and students or just the teacher)
2. Discourse initiative (power and control, more open or closed to students' initiative)
3. Symmetrical or asymmetrical orientations related to the types of knowledge being addressed
4. Level of interanimation of ideas (low level, when the students points of view are elicited but not further considered; high level, when the scientific perspective is constructed upon – or in opposition to – everyday reasoning)

To understand why dialogic discourse is so rare in educational practices and to develop ways to improve the quality of classroom talk, it is necessary to consider the culture and institution of schooling. Dialogue in the classroom setting must involve a real desire for mutual comprehension and the contrast of perspectives, but the teacher is in an institutional position that reinforces a resolution in the terms of the accepted scientific perspective. So, even in innovative classrooms, dialogic discourse is usually orchestrated by the teacher, who aims to control the flux of ideas in order to achieve, at the end, the scientific perspective as the best alternative.

In one sense, an ideal concept of dialogue in its radicalism has no room in school settings, as the participants of dialogue are not equally open to be convinced by the others. Besides, while there are multiple points of view being considered, they are not equipollent and equipotent in the manner Bakhtin identified in his analysis of the polyphonic novels of Dostoevsky. According to Bakhtin, two voices are considered equipollent and equipotent when they have equal force, power, and significance. In the novels of Dostoevsky, characters are considered from very different perspectives. The author did not take part in the debate; he has just presented the character's worldviews as poles of human understanding in social life. On the contrary, in school science teachers are always committed to the scientific perspective or, in other words, to the resolution of differences according to a certain position for the knowledge to be constructed. Thus, the institution of schooling constrains the ways in which dialogue can be conducted in the classrooms.

Dialogic Teaching Includes Both Dialogic and Authoritative Discourses

Teaching science involves two complementary dimensions that point in opposite directions but are not mutually exclusive. The first dimension relates to cultural heritage. Science, as a public knowledge, allows a picture of the world that often differs significantly from the perceived world of everyday life. Thus, science education demands guided interventions and supports so that the most important scientific ideas can be assessed and reviewed by the new generations. In this sense, teaching science involves a commitment to concepts, models, forms of reasoning, and language stabilized and agreed by scientific communities. Such forms of knowledge point to the past of science and ensure a collective memory for a given community. This is true both for the training of future members of communities of experts and also for ordinary citizens in contemporary societies.

The second dimension concerns personal understanding of science as a way to see and act on the world. Here science may be seen as a process of understanding the world, one that demands critical consideration of knowledge claims, argumentation based on evidences, and a sense of uncertainty faced to the phenomena to be explained. For this to occur, it is essential to design teaching situations in which students are asked to critically examine their views, as well as the scientific views that have been introduced.

Hence, to be implemented in schools, dialogic teaching involves both cultural transmission and meaning making of new ideas, by alternating both authoritative discourse and dialogic discourse. That is to say, scientifically productive classroom dialogue requires instruction that allows not just opportunities to discuss different ideas but also guidance to the new ways of thinking. According to Scott et al (2006), these two forms of discourse are not mutually exclusive, but complementary:

> The tension [between dialogic and authoritative discourse] develops as dialogic exploration of both everyday and scientific views requires resolution through authoritative guidance by the teacher. Conversely the tension develops as authoritative statements by the teacher demand dialogic exploration by students. So, both dialogicity and authoritativeness contain the seed of their opposite pole in the dimension, and in this way, we see the dimension as tensioned and dialectic, rather than as being an exclusive dichotomy (Scott et al. 2006, p. 623).

These two modes of discourse – dialogic and authoritative – accomplish different functions and can be engendered in different moments of a sequence of teaching. On one hand, authoritative discourse, focused on transmission of culturally accepted ways of thinking, allows cultural anchorage and a fidelity to scientific views. On the other hand, dialogic discourse provides opportunities for students both to make explicit their everyday ideas at the start of a teaching sequence and to apply and explore newly learned scientific ideas for themselves.

Ways of Promoting Dialogic Discourse in Science Classrooms

Due to the culture of schooling, dialogic teaching does not happen spontaneously. Therefore, it is important to consider teaching and discursive strategies designed to improve dialogism in science classrooms.

The stronger dialogic teaching design is related to inquiry-based teaching. According to Wells:

> When students pursue investigations, they develop ideas and acquire information that they want to share and debate; at the same time, the problems they encounter call for the joint consideration of alternative possible solutions. In these circumstances, students have reason to learn the skills necessary for engaging in productive dialogue and, over time, they also develop the disposition to approach problem solving of all kinds in this way (Wells 2007, p. 265).

Besides the importance of such approaches, even in countries and schools where educational reforms aim at promoting inquiry-based teaching, there is evidence that dialogic discourse is still rare in the science classrooms. One reason is that teaching materials do not offer necessary support for teachers to change the way language is used in classrooms and to know how to move from students' ideas to abstract scientific concepts.

There are research efforts to design teaching sequences in which the types of discourse around activities are in focus. The interplay between everyday and scientific knowledge involves planning turning points between dialogic and authoritative discourses. The study of such turning points – how and when they happen – is considered a crucial aspect to both understand and promote dialogic teaching.

Among the discursive strategies to improve dialogism in science teaching, there is a strong concern about the type of teacher's feedback. Many studies indicate the need for fewer evaluative statements from the teacher and more prompts and follow-up moves intended to encourage students to come up with new ideas, clarify their positions, and comment on other's points of view. The teacher's types of questioning are crucial to developing more dialogic whole-class discussions. Classroom studies also emphasize teacher's comments to the students' utterances, which allow the continuity of discourse and co-construction of knowledge. In some cases, this is done by "revoicing" the students' previous contributions, thus providing a collective memory to the class and encouraging further developments.

Dialogic discussions, in which students try out ideas and use language to think together, are more likely to occur in peer interactions and group work, free of teacher interventions. Besides, giving students time to prepare their thoughts about an issue or questions prior to a whole-class discussion greatly increases the diversity and quality of contributions. However, successful group work requires preparation, guidance, and supervision, that is to say, a balance between dialogic and authoritative discourse.

Preliminary dialogic discussions in the early stages of a new topic are commonly recommended by educational reforms and highlighted by many science classrooms studies. The purpose of such "exploratory talk" is to explore students' views about the topic and to connect these views to the scientific perspective to be introduced (Mortimer and Scott 2003).

Studies of science classroom discourse show that the move from authoritative to dialogic discussions at the end of teaching sequences, as advocated by Scott et al. (2006), is much less frequent than the use of dialogic discussions in the opening activities. Although teachers around the world are much more willing to explore students' views, the same is not true in respect to giving more space to students to discuss new contexts of use of the recently learned scientific ideas. Another reason is that the commitment of teachers to the scientific correct view is stronger than their belief in the need for responsibility to be transferred to the students in extending the scientific perspective to new contexts.

These activities may involve inquiry tasks in which the students are invited to work within the new scientific ideas. Another possibility is to promote the awareness of conceptual profile by comparing the results of pre- and post tests designed to address the differences between everyday and scientific perspectives on the topic.

Nowadays teachers around the world are facing a dilemma between promoting meaningful learning and being sensitive to the pressure for results in assessments. These assessments always reduce the dialogic space available in the classroom, as the pressure is to prepare students to give the right answer and not to discuss and justify points of view. Besides this, each new trend in the curriculum, instead of relieving this pressure, increases it with new demands on teaching.

Final Comments on the Issue

Based on this review, there is a clear need for more studies in dialogic talk at the end of a teaching sequence, when the students, working together, take the responsibility to use the scientific perspective to construct an explanation to new problems. It is also necessary to develop teaching sequences that use different strategies to link scientific and everyday points of view, highlighting the discursive strategies and communicative approaches to be used along the activities.

Sociocultural approaches in education mean to work in the tension between construction and instruction, discovery and transmission, freedom to explore, and guidelines to follow-up. Dialogic teaching may involve moves between these two types of discourses, dialogic and authoritative, to allow the active reconstruction of existing knowledge.

Today, the challenge is how to incline this balance to the dialogic side. There are many ways to do that: preparing teachers to do dialogic discourse in classrooms, designing teaching sequences in which the students should consider different alternatives to explain a phenomenon, providing links between phases and activities along a teaching sequence, preparing teachers to give feedbacks and prompts that guide the participation of students in dialogic discourse, and being conscious of the need to talk about ways of talking in classrooms. Besides that, there is a need to improve the effectiveness and impact of dialogic discourse in teaching sequences.

Instead of listing ideal features of dialogic discourse or dialogic space, we should understand that dialogue in school is both driven and bounded by predetermined curricular content and objectives. This is a clear constraint for those who think about dialogue as a completely open space for joint construction. However, scientific knowledge has no meaning for students and citizens if there is no interchange and communication between everyday and scientific domains.

Cross-References

- ▶ Acculturation
- ▶ Action and Science Learning
- ▶ Alternative Conceptions/Frameworks/Misconceptions
- ▶ Collaborative Learning in Science
- ▶ Discourse in Science Learning
- ▶ Inquiry, Learning Through
- ▶ Language and Learning Science
- ▶ Socio-Cultural Perspectives on Learning Science

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Didactic

▶ Didaktik

Didactic Transposition

► Transposition Didactique

Didactical Contract and the Teaching and Learning of Science

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Introduction

The concept of *didactical contract* provides a powerful way of interpreting aspects of teaching, learning, and the interactions between teachers and learners. This concept has been developed over many years of experimental and theoretical research on didactical situations in mathematics. (Brousseau 1997).

For epistemological reasons, each "didactical contract" is to a large extent specific to the knowledge being taught. This specificity explains why the use of this concept has as yet expanded so little into other disciplines, although it has great potential in these.

In addition, the observation and explanation of various phenomena has led to the extension of the concept of didactical contract to the relationships of all the parties involved in education: parents, society, administration, academic societies, etc., always with respect to a specific (mathematical) concept.

Didactical contract has a great potential for enhancing our understanding of aspects of the teaching and learning of science. In the concluding section of the entry, some ways in which *didactical contract* has this potential are very briefly explored.

Didactical Contract and Mathematics Education

Definitions

The teaching of mathematics is a social project of putting at the disposal of all the members of a society the means of participating in a common mathematical culture and benefitting from it. To each precise notion to be taught, the partners in teaching (i.e., the teacher, the learners, and the other parties mentioned above) associate expectations, obligations that each undertakes and benefits from, and the means by which they envisage (mutually or separately) satisfying these expectations and obligations as well as the consequences of not satisfying them.

A *didactical contract* is, in the broad sense, an interpretation of the set of these expectations and obligations, be they compatible, explicit, and agreed to or not. The study of the didactical contract in any classroom cannot be made solely by direct observation because a large part of these expectations and perceived obligations cannot be made explicit by the partners. Observation must therefore be complemented by modeling and experiments.

The Two Components of the Contract: Devolution to the Students and Institutionalization of Their Results

In mathematics education it is essential to know at every moment who, among the teacher, the students, and the wider *milieu* in which they are embedded, will take the responsibility for each mathematical statement that appears in class.

For example, during *autonomous activity* undertaken by students (such as the solving of a problem or more generally participation in a mathematical situation), the teacher refrains from any specific informative intervention.

This autonomous mathematical activity must be preceded by a phase of *devolution*, in the course of which the teacher provides information (e.g., a "direct" teaching [a lecture], exercises, assignments, etc.) that:

Allows him/her to move epistemological responsibility for what happens during the private

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or public development of the activity from teacher to student

Allows the students to then take on the responsibility offered to them during the mathematical activity

This mathematical activity of the students is followed by a phase of *institutionalization*, for the students and the teacher, consisting after an autonomous activity of:

Taking note of what has happened, of questions that have been resolved or are still open/unresolved, and of errors uncovered and removed in the course of the autonomous activity

Recognizing the new results obtained by the students if they conform to expectations and standard usage and the progress of routines that are in the course of being acquired

Classifying established pieces of knowledge that are well shared as references that may henceforth be used in class activities

Pointing out the questions that have not been resolved and the challenges to ponder

The nodal point of the didactical relationship is *devolution*. Devolution is the heart of the didactical contract, and is treated in a separate entry. The devolution of the right and capacity to express a personal mathematical thought is the essential act of teaching of this specialty. The study of it reshaped the foundations of the theory of didactical situations in this domain. But every discipline must address the devolution to the student of specific essential powers and rights; the prospects for and reality of devolution in the teaching and learning of any discipline undoubtedly merit studies similar to those already taking place in mathematics education.

Origin

The notion of didactical contract first emerged in 1980 in the course of a statistical and clinical investigation of some students having difficulties in mathematics but not other subjects (1975–1980). One of the cases observed gave a glimpse of certain causes of divergences and natural misunderstandings between the reciprocal expectations and possibilities of the teacher and student (Brousseau and Warfield 1998). Gaël, 8 years old and quite intelligent, responded to a problem involving looking for the unknown term in a sum in the manner of a 4-year-old. He happily refused to accept responsibility for the truth of what he said and thus did not enter into any solution procedure or, especially, a search procedure. This difficulty made starkly apparent the theoretical impossibility of forcing a child to take on a mathematical situation. The case was resolved by a sequence of situations – of "contracts" – to which he gave his agreement. But the theoretical problem remained and revealed profound flaws in the classical conceptions of the teaching of mathematics.

This concept of didactical contract then made it possible to explain observations such as the following (real example). Some teachers posed to their students absurd questions like the following: "On a boat there are 15 goats and 26 sheep. How old is the captain?" The students added up the numbers and said "41 years old!" Some commentators were outraged, claiming positions such as "Teachers are making students more stupid rather than more wise!" Further investigation revealed that the students thought the problem was absurd. When asked why then they answered it, they replied "Because the teacher asked [the problem]!" "And if the captain was 53 years old?" "The teacher didn't give us the right numbers!"

Put in simple terms, the notion of didactical contract provides a most plausible explanation for this student behavior: Past experience had led these students to the intuitive view that the quite implicit "contract" under which their mathematics classroom operated was that whenever the teacher asked a question, their responsibility was to answer the question and no more than this. They were certainly not to query the question, to suggest the question made no sense, or to suggest it was silly, and so on. A similar experiment with teachers in training gave the same results, with the same explanation being once more most plausible.

After its emergence in 1980, the concept of didactical contract was put to the test in the Centre de Recherches sur l'Enseignement Elémentaire des Mathématiques (the Center for Research on the Elementary Teaching of Mathematics – the COREM), which was conceived by G. Brousseau and created by the Institut de Recherche sur l'Enseignement des Mathématiques (Mathematical Education Research Institute – the IREM) of Bordeaux. The COREM functioned from 1973 to 1999 and comprised a scientific laboratory associated with a school with 14 classes of students aged 3-12, set up to permit scientific observation and the realization of long-term experiments on the teaching of mathematics in a controlled and limited context (Davis et al. 1986).

The didactical contract in the classroom depends tightly, but in a complex way, on the conceptions and requirements of various social and cultural institutions relative to each mathematical notion. The numerous phenomena that can only be explained by these interactions constitute the field of *macrodidactique*. This is discussed further in section "Macrodidactique."

Paradoxes of the Didactical Contract

Consider the usual classroom situation where the teacher wants to teach part of what she knows to a student who does not know it. There are a number of paradoxes inherent to this situation, paradoxes that in some contexts are in fact genuine contradictions.

(a) *Fundamental paradox*. The student cannot commit himself to a project about which he does not know the central issue, the precise objective, that is, the essential element of knowledge that is the focus of the project. Nonetheless, his engagement is indispensable – without it the teacher cannot achieve her goal. The teacher's engagement is as well, but she cannot commit herself about the certain success of a designated student. Every didactical contract is in effect a gamble – a necessary illusion.

(b) *Paradox of devolution*. The knowledge and will of the teacher must become the knowledge and will of the student, but what the student knows or does by the will of the teacher is not done or decided by his own judgment (a paradox similar to Husserl's of the master and the slave). The didactical contract finds its success only when it is broken: The student takes on responsibility for what he does or knows, independently of the teacher, and refuses her support.

(c) *Paradox of the said and unsaid* (a consequence of the preceding paradox). It is in what the teacher does not say that the student can find what he can say himself. The unsaid, the inexpressible, the uncertain, and sometimes even the false are the instruments of a living thought that establishes a truth and produces conviction about the reference knowledge.

(d) *Paradox of teleological learning*. A lecture turns the exposition of the conclusions of an historical creation, reorganized to follow deductive logic, into a prerequisite condition for student learning. Thus, the student is supposed to make use of what he will not know until the end of the process to organize first his comprehension and then his learning. He believes that in order to solve a problem, he must first "know" its solution.

(e) *The paradox of the general and the specific*. The teacher can only engage in procedures that are relatively general and common, for example, theorems, whereas the acquisition of a piece of knowledge is an individual and specific adventure of the knowledge in play in the problem.

(f) *Paradox of the actor*. Teaching is a production. The teacher needs to be a professional actor who must feign rediscovery with her students of knowledge that is highly familiar, even an old habit for her. The more she tries to be "natural" and spontaneous, the less credible and effective she will be (Brousseau and Otte 1991).

(g) *The paradox of uncertainty*. Knowledge is manifested and learned by the reduction of uncertainty that it brings to a given situation. Without uncertainty, or with too much uncertainty, there is no adaptation, and no real learning. The optimal development of individual or collective learning is thus accompanied by a normal optimal rate of errors. Global success is not a monotone function of the rate of instantaneous success. Arbitrarily augmenting or reducing it thus impedes and may delay both individual and collective learning (but the latter makes it possible to see to it that it is not always the same students who are doomed to provide the necessary errors.) The result is a new paradox: An increased rate of "instantaneous" success in the course of learning does not prove a better overall effectiveness.

(h) *The paradox of adaptation or lack thereof*. Excessive or premature adaptation to a piece of knowledge in conditions that are too specific can result in a particular piece of knowledge that may constitute an *epistemological obstacle* to the adaptation of this knowledge to new conditions (e.g., the practice of division in the natural numbers is associated to a meaning [sharing] that is an obstacle to its presentation in the decimal numbers when one needs to divide a number by a larger number [e.g., 0.3/0.8]).

(i) *The paradox of rhetoric and mathematics*. In order to construct the mathematical knowledge of students and its logical organization, the teacher uses various rhetorical means to capture their attention. The culture, pedagogical procedures, and even mathematical discourse abound in metaphors, analogies, metonyms, substitutions, figures of speech, etc., of nonmathematical means, against which mathematical concepts are often constructed.

(j) *The paradox of culture and science*. The teacher is thus supposed simultaneously, as a specialist, to cause the rejection of what science has disqualified and, as one who institutes students into a culture, to teach that culture with its historical meanderings.

Division of Responsibilities Between Requesters and Holders of Knowledge

The following types of contract do **not** cause the initiator to engage directly with the initiated, or vice versa:

Esoteric contract. The *client* (i.e., the learner) poses a question and is responsible for the question, its relevance, and the use of the response; the *expert* (i.e., the teacher) provides that response and guarantees its validity without saying how he established it.

Exoteric contract. The *scientist* produces the question and the answer, of which she gives the proof; she shares the responsibility for it with her community. The philistine takes on that of the relevance and use.

Initiatory contract. The *initiator* shows how he conceives of the knowledge. He comments on it, accompanying it with appropriate examples and their solution. He thus guarantees the validity and pertinence of the knowledge presented but takes no responsibility for what the person being initiated does with it.

Contract of instruction. The *instructor* proposes exercises and takes cognizance of the responses of the *learner*. She corrects them and gives the explanations that are asked of her. She makes no guarantees about the learning.

The types of contract where the teacher undertakes to achieve a certain success from the learner are as follows:

- The *strong didactical contract*. The teacher commits himself to initiating a specific protocol, known to make it possible to obtain with a certain frequency the behaviors agreed to be characteristic of some precise piece of knowledge. He thus relies on a custom, a culture, or a science recognized by the partners (parents, society, administration, academic societies, etc.), to achieve an average result agreed to by the partners. The fact that some of the students have succeeded in learning the agreed knowledge suffices to prove that it has been taught. An obligation of the mean has been satisfied.
- The *commercial contract*. If the scientific or cultural references are shared by the partners and only under that condition, teaching may be made the object of a *commercial contract* for collective or individual teaching. Nonetheless, the client would be mistaken to believe, like the Tyrant of Syracuse, that he could thus purchase a nonexistent royal road. It would be an even greater error to believe that random punishments of the students, of their teachers, or of the didacticians could produce improvements that depend in fact only on our shared knowledge. The height of absurdity is reached

when it is the client-students themselves who wish to exercise this type of empirical control over the processes that involve them.

Observation of the Spontaneous Responses of the Teachers and of Their Effects

The reactions of a teacher to an error or a failure of the students are combinations of a finite list of types, depending on:

- Certain criteria of the situation. Whether the error is recognized or not, explicit or not explicitly or implicitly, whether it is partial or global, and corrected or not (abandonment without explanation or, worse, without correction is not well accepted in classical contracts)
- The means used to reduce uncertainty. Identical repetition or metonymic or metaphorical repetition (reformulation, analogy, change of context), decomposition either of the problem (into intermediate questions) or the class (into level groups), analysis at the meta-level (logical, mathematical, heuristic or graphic reminders or comments), etc.

While these types of responses are implicitly fairly well accepted in the strong didactical contract, their properties are very rarely recognized. Sustained observation and theoretical analysis have convinced us that no combination of these types of response is in all cases either better or worse than all the others. None is decisive in all circumstances. Only analysis of the particular situation makes it possible to bring out the optimal choice case by case. Bernard Sarazy has demonstrated experimentally the importance of didactical flexibility: Varying the types of response is the best strategy (Sarrazy B 2002).

Thus, nonspecific pedagogical methods, principally based on the hypothesis of the universality of cognitive processes and hence of methods of learning and hence, a priori, of the existence of valid general methods of teaching, cannot provide optimal teaching. Thus, the use of "universal" responses, theories, and methods may simplify the acceptance by the population of a pedagogical or didactical contract and lower the cost of work and of training teachers, but it cannot under any circumstance be the best response to the expectations for teaching.

Macrodidactic

The above hypothesis led to the study of the influence of the epistemological, scientific, cultural, social, or economic foundations on the didactical contracts currently in operation in different societies. The issue is to explain the expectations, the offers, and the demands of different components of society with respect to this or that specific piece of knowledge and to compare these expectations, offers, and demands with the possibility of responding.

This new field of research has developed over the last decade under the name of "Macrodidactique." It has offered explanations for phenomena like the failure of the reforms of teaching based on mathematical structures in the course of the twentieth century (New Math), that of the teaching of "problem-solving methods," the effects of standardized testing, etc.

By bringing out the effects of the beliefs and inappropriate requirements of various partners in the didactical contracts, this research makes it possible to look into current practices in a more scientific and convincing way. For example, determining which knowledge to teach only on the basis of an explanatory text, without mentioning the actual practices that have produced the knowledge, has contributed to the creation of a didactical fiction which today is an insurmountable obstacle to progress in that domain.

Didactical Contract in Science Education

The word *contract* is most commonly used to indicate an agreement – usually a legal one but sometimes not – between two or more groups or individuals. That use is most certainly pertinent here, although, equally certainly, not "legal" in the usual way. The essence of this construct that there is a "didactical contract" developed over time and very often implicitly between teacher and students is an intriguing and very valuable frame for considering the behaviors and dynamics in any classroom of any subject. It raises a range of critical questions for considering classrooms, for example: What teaching and learning behaviors are expected of each group (teacher and students) in this classroom? Why are these expected? Do students or teacher know that these expectations exist? etc.

Perhaps more significant is that the evolution of the construct in mathematics education has consistently pointed to the impact on the contract of the nature of the content that is the focus of the classroom at a given time.

To what extent are these studies relevant for the teaching of other disciplines, most particularly science (and more generally for education)? Monitoring the meaning of concepts by their use in precise situations is normal in all disciplines and particularly so for mathematics and science. But the heart of the didactical situation is a situation specific to the knowledge in question. Apart from a few general principles and a few methods, each notion poses by definition a problem that is specific to itself.

The interaction between both the teaching and the learning of "X" and the epistemological and ontological nature of "X" has received very occasional attention in the science education literature, but as yet far too little. This is the case even within the branches of science. For example, consider the content of "introductory mechanics" and "introductory DC circuits." At one level one might argue that these are very similar content areas and can be taught with the same broad pedagogical approaches – both involve difficult relationships between concepts and have disarmingly simple formulae that often "hide" the conceptual difficulty in these relationships; both are rich in student alternative conceptions that have profound impact on subsequent learning. But there are profound differences in the nature of the knowledge in each area: In mechanics observations are almost always direct (i.e., we do not need instruments to enable the observation), and analogies and models are almost never used; in electricity, on the other hand, observations are always indirect (can only be made via instruments) and analogies and models are so central that even the language used to talk about the knowledge is totally dependent on analogies and models. To make the point further, consider then the differences they will need to be in the didactical contract between teacher and students in the very specific context of the physics laboratory for investigations of phenomena in mechanics and in electricity.

Cross-References

- ▶ Communities of Practice
- ▶ Conceptual Change in Learning
- ▶ Constructivism
- ▶ Dialogic Teaching and Learning
- ▶ Didactical Situation
- ▶ Dilemmas of Science Teaching
- ▶ Metacognition and Science Learning
- ▶ Metaphors for Learning
- ▶ Milieu
- ▶ Motivation and the Learning of Science

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Didactical Situation

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Keywords

adidactic; Equilibration; Mathematical concepts; Milieu

Imagine a teacher who knows that she/he must miss a class next week and wants to communicate the lesson plan to a replacement colleague. How might the teacher convey the critical features of the lesson so that the colleague can reproduce (1) the same learning outcomes for the students and (2) the same meanings for the knowledge acquired by the students? One of the aims of the theory of didactical situations (hereafter denoted TDS) is to identify the critical conditions for situations that can be presented to students and within which students will carry out activities that will enable them to construct specific meanings and understandings of a given concept.

Several dimensions are intertwined in a teaching situation focused on specific learning outcomes. These dimensions include cognitive, epistemological, cultural, and social concerns. Hence, several theoretical frameworks have contributed to the development of TDS. One such framework is Piaget's theory of "equilibration"; this theory served a pivotal role in the evolution of the idea of "adidactical" adaptation. In this conception, students construct knowledge by becoming directly engaged in solving a novel problem, refining their concepts and strategies in light of feedback from a (material and social) milieu (Brousseau 1997).

Conceiving of knowledge as resulting from a social construction over a long period of time led to the development of the theory of didactical situations, starting from the hypothesis that knowledge cannot be reconstructed in a spontaneous equilibration process. Instead, conditions and environments must be organized to present students with questions or problems that require a reorganization of their thinking. Here, "situation" refers to a collection of problem-solving tasks and environments designed to evoke a particular form of adaptation on the part of students, supporting them in the process of knowledge construction.

A Theory of Relationships Between Situations and Knowledge

Conditions for learning a scientific concept are specific to the content being learned. TDS was originally used to model learning situations in mathematics, but it can be viewed as a theory of the relationship between situations and knowledge so it can be extended to, or reinterpreted in, the sciences. The notions of economy and coherence are central in these relationships. Knowledge in physics, mechanics, or biology provides coherent and unified interpretations of families of phenomena that can be seen as different. As such, the knowledge groupings provide economy in explaining these phenomena. For example, describing two objects at rest as an event involving action facilitates provision of a unified account of the actions of one object on the actions of another object, irrespective of whether there is motion or not (Ruthven et al. 2009).

Identifying this type of economy or coherence for specific mathematical and scientific concepts, therefore, requires an epistemological analysis. This may include an analysis of the genesis and growth of the concepts in the histories of mathematics and the sciences, especially in order to determine the extent to which obstacles are intrinsic to these concepts. The notion of "epistemological obstacle," originating from Bachelard's theorization of the growth of knowledge in the physical sciences, was extended by Brousseau for theorizing the learning of mathematics: "obstacles… from which one neither can nor should escape, because of their formative role in the knowledge being sought" (Brousseau 1997, p. 87).

Adidactical Versus Didactical

The distinction between an "adidactical situation" and a "didactical situation" is key to understanding the distance between Piaget's cognitive equilibration theory and TDS. "Adidactical" does not mean that no teaching intentions underlie the situation; it refers to the perspective of the student. In an "adidactical" situation, the student experiences the problem not as a problem created by the teacher with didactical intentions but as if it were a genuine problem similar to problems that can arise in her/his life outside of school and that she/he must solve.

Although the situation is conceived with didactical intentions, the way the problem is posed and its environment lead the student not to consider the teacher's expectations but rather to take ownership of the problem. The solving processes may include some equilibration processes to overcome cognitive conflicts.

However, although an early assumption in the development of the TDS was that teaching sequences could be organized around adidactical situations alone, it turned out that, when observing their implementation in the classroom, the theory did not take into account "the [inescapable] intervention of the (mathematical [or scientific]) culture through the medium of the teacher" (Brousseau 1997, p. 110). It led to the incorporation of a further stage of "institutionalization" in which the knowledge that students developed from an adidactical situation undergoes a process of socialization and codification through teacher interventions. The asymmetry of the positions of the teacher and the students, with regard to mathematical and scientific knowledge, and the role of language in conceptualization, as laid out in Vygotsky's theory, are also sources of TDS.

As stated above, the guiding epistemological hypothesis in TDS is that a mathematical concept takes its meaning from problems to which it brings an optimal solution. This epistemological hypothesis could be extended to the sciences to the extent that scientific concepts take their meanings in relation to the variety of situations of their fields of applicability. The corresponding cognitive hypothesis within TDS is that learning results from students adapting their thinking in response to some new situation where their existing knowledge does not support an efficient solution strategy. The solution pathways that students find it necessary to devise serve as the sources of new knowledge. Epistemological and cognitive considerations are, of course, not independent: the aim is to identify the conditions for a planned process of learning through which students construct knowledge and use those features which the epistemological analysis has identified as constituting the concept to be acquired.

The teaching sequence is organized around a succession of adidactical situations based on problems. This forms a learning progression in which the question proposed to students at each new stage arises from problems encountered in deriving solutions at the previous stage or from the consequences or developments of these solutions. This succession does not depend only on the prior epistemological analysis, but also on concerns of the local organization and functioning of particular situations within the teaching sequence. Collective sessions, gathering the various solving processes of students under the guidance of the teacher, take place between adidactical situations.

An adidactical situation depends on the problem being one where students have a starting strategy available to them, but this strategy turns out to be unsatisfactory in some way. The ideal is that students, as a result of observing the inadequacy of the initial strategy, will be motivated to look for an alternative strategy and that this will lead them to devise a solution strategy that provides a basis for constructing the intended new knowledge.

Thus, it is of crucial importance that students should become aware of the inadequacy of their tentative solutions and that they should receive information from the situation that enables them to move forward in developing more powerful solutions. The notion of "milieu" has been developed within TDS to refer to that component of the situation that offers possibilities of interaction with students, providing means of gaining feedback to validate or invalidate their solution strategies. Particularly where younger students are concerned, the milieu is often designed to capitalize on a context with which students are already familiar. This familiarity guides the opening exchanges between the situation and the students. Changing the context for each particular situation in the teaching sequence is impractical as it would require students to spend time coming to terms with a new context on each occasion. Moreover, if the same context can be maintained, students' greater familiarity with it facilitates their further exchanges. Finding a suitable context capable of serving over several sessions is therefore a critical issue in the "staging" phase of a teaching process.

The milieu is not only a material milieu but it may develop and incorporate scientific texts, arguments in a classroom discussion, and the prior knowledge of students. This is particularly the case for introducing explanatory models in the experimental sciences. Students cannot themselves elaborate scientific models. The Leeds research group (Ruthven et al. 2009) presented lower secondary school students, learning the behavior of electrical circuits, with a contradiction between their expectations and what happened in the material milieu. The teacher proposed a simple series circuit with a power source at one end of the room and a bulb at the other end with very long wires connecting the circuit together. Many students expected a short delay between connecting the circuit and the bulb lighting. This is not what happened and it was very clear for students; however, students could not build an explanation by themselves. The teacher had to introduce an analogy to the class to explain the behavior of the circuit. Orange (2007) proposed to distinguish between three kinds of milieu for modeling learning situations in experimental sciences like biology: the external milieu, the internal milieu of the student, and the internal milieu of the classroom made of explanations and interpretations socially accepted and shared in the classroom.

In TDS, the social organization plays an important role in the functioning of the milieu. Adidactical situations that aim at fostering the learning of the formulation of mathematical objects and relations are based on exchanges between two students. Student A and Student B build a team and they must solve a problem in a constrained environment. Student B has access to information for solving the problem only through Student A who must convey useful information (verbally or in writing) in a form that is understandable to B. Whereas A and B are partners in a formulation situation, in adidactical situations that aim at the learning of proof, A and B are opponents: Student A needs to win against Student B by formulating arguments that student B can never invalidate.

Didactical Variables

In a task, there are identifiable variables with values that condition the efficiency of specific solving strategies and that make alternative strategies inefficient or tedious. For example, comparing the size of two collections of objects calls for totally different strategies depending on whether the two collections can or cannot be seen simultaneously. If the two collections can be seen together, a counting strategy is not necessary, whereas if it is only possible to have access to each collection separately, counting becomes unavoidable unless the collections have a small number of objects and can give rise to a mental image. Thus, at least two didactical variables can be identified in this comparison task: the size of the collections and the type of access to them. Another variable is the presence or absence of the possibility of manipulating the objects – since the counting process is greatly assisted by the possibility of separating already counted objects from those not yet taken into account. In the previous example about circuits, the length of the wires is a variable that makes visible the erroneous character of a sequential and causal idea about circuits. Such variables are called "didactical variables" because they act as key levers in precipitating and managing the development of the expected trajectory of learning. Identifying such variables starts from analysis of the knowledge available to students, in particular knowledge of the procedures available to them for dealing with the task. Observation of how situations play out with students in the classroom may reveal further variables not identified through prior analysis.

Use of TDS

During its development, the theory of didactical situations gave rise to the design of teaching sequences which, when examined in the classroom context, led to modifications and refinements of the theory. Warfield (2007) offers an introduction to the theory by giving examples of sequences of situations that allow the reader to better understand the use of the theory. For about 20 years now, the theory has also served as a tool for analyzing the design of teaching sequences and their implementation. A notion such as that of the didactical variable can be used independently of TDS to analyze tasks and gain some predictive ideas about the way students would deal with them. Ruthven et al. (2009) interpret TDS as an "intermediate" theory assisted by the "adidactical situation" and "didactical variable" tools. TDS is also used in conjunction with other theories such as the anthropological theory of didactics for analyzing the progress of teaching as a change of positions of students and teachers with regard to knowledge (Sensevy et al. 2005).

Cross-References

- ▶ Didactical Contract and the Teaching and Learning of Science
- ▶ Learning Progressions
- ▶ Longitudinal Studies in Science Education
- ▶ Milieu
- ▶ Scaffolding Learning
- ▶ Socio-Cultural Perspectives on Learning Science

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Didaktik

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The European Science Education Research Association (ESERA) states in its constitution: "*Wherever the English phrase 'Science education' appears in this document, it has a meaning equivalent to 'didactique des sciences' in French, 'Didaktiken der Naturwissenschaften' in German, 'Didáctica de las Ciencias' in Spanish, or the equivalent in other European languages.*" At least in continental Europe, the term "Didaktik" is widely used – however with a number of significantly different meanings that do not only concern subtleties.

The German *Didaktik* tradition (i.e., the tradition that has developed in the German-speaking countries) has been very influential in continental European countries – however to differing extents. In ancient Greek, the word *Didaktik* denotes actions of showing and indicating. While this meaning seems to be quite close to that of the English word "didactical," *Didaktik* as discussed here stands for a multifaceted view of planning and performing instruction. It is based on the German concept of *Bildung* which refers to the formation of the learner as a whole person. It concerns the analytical process of transposing (or transforming) human knowledge (the cultural heritage) into knowledge for schooling that contributes to Bildung. Clearly, this transposition viewpoint is a key feature of thinking about science instruction in terms of Didaktik.

Many recent attempts to improve science teaching and learning have put their major emphasis on changing teaching methods and approaches. But the science content structure *for* instruction should also be given significant attention. This is a key figure of thought within the Didaktik tradition. The *Educational Reconstruction* approach explicitly draws on it. The analytical process of transposing human knowledge into knowledge for schooling is at the heart of this approach. It has become a key concept of German science education and seems to be widely accepted within European science education.

A project was carried out in the 1990s by the German Institute for Science Education (IPN) in Kiel to investigate the differences and commonalities between the European *Didaktik* tradition and the more pragmatic Anglo-Saxon *Curriculum* tradition. Westbury (2000) points out that Wolfgang Klafki (1995), one of the most distinguished scholars in the Didaktik tradition, argues that American curriculum theory and Didaktik are not far apart, as they are concerned with the same set of issues. Westbury points to key differences between the Didaktik and Curriculum viewpoints. He argues that the Curriculum viewpoint is embedded within a pragmatic philosophical position. Accordingly the focus is on *how* things are enabled, while the Didaktik tradition predominantly focuses on the *why*. Hence, he comes to the conclusion that despite the commonalities of the two positions, there are also "fundamental tensions because of their very different culturally embedded starting points" (p. 36).

There have, however, been important developments since Westbury presented his analysis. Globalization of science education research has resulted in close cooperation of science educators around the world. These processes initiated a fruitful international debate on the various science education positions, which have not resulted in a uniform view but more often in the enrichment of national (or regional) views. More recently, in the United States of America, for instance, there have been serious attempts to analyze and discuss critically the European Didaktik position. Duschl et al. (2011), for example, claim "*that didaktik research is a good source for identifying conjectural pathways of learning that can be examined as learning progressions*." This claim is of particular significance as research on learning progression has become a major strand of science education research in the USA.

In order to illustrate the German *Didaktik* perspective discussed above, two key approaches will be briefly presented. The first is Klafki's *Didaktische Analyse* (Educational Analysis) published in 1969. His ideas derive from the concept of Bildung and rest upon the principle of primacy of the aims and intentions of instruction. These frame the educational analysis, at the heart of which are the five questions in Table 1.

Didaktik, Table 1 Key questions of Klafki's (1969) Didaktische Analyse (English Translation: R. Duit)

(1)	What is the more general idea that is represented by the content of interest? What basic phenomena or basic principles and what general laws, criteria, methods, techniques, or attitudes may be addressed in an exemplary way by dealing with this content?
(2)	What is the significance of the referring content or the experiences, knowledge, abilities, and skills to be achieved by dealing with the content in students' actual intellectual life? What is the significance the content should have from a pedagogical point of view?
(3)	What is the significance of the content for students' future life?
(4)	What is the structure of the content if viewed from the pedagogical perspectives outlined in question 1?
(5)	What are particular cases, phenomena, situations, and experiments that allow making the structure of the referring content interesting, worth questioning, accessible, and understandable for students?

Another significant line of thought within the German *Didaktik* tradition is the fundamental interplay of all of the variables determining instruction (Fig. 1) proposed by Heimann et al. (1969). In this model, students' learning processes are of key interest. The aims and intentions of instruction are the starting point for the process of designing instruction. The *interaction* between intentions and the other variables shown in the top row of Fig. 1 is given particular attention. Students' intellectual and attitudinal preconditions, as well as sociocultural factors, significantly influence the interplay of these components. They enable four key questions to be raised that shape the process of instructional planning: Why – What – How – By What.

It seems that attempts to improve science teaching and learning usually put a strong

Didaktik, Fig. 1 On the fundamental interplay of instructional variables (English Translation: R. Duit)

Intentions (aims and objectives)	**Topic of instruction** (content)	**Methods** of instruction	**Media** used in instruction
Why	**What**	**How**	**By What**
Students' intellectual and attitudinal preconditions (e.g., pre-instructional conceptions, state of general thinking processes, interests and attitudes) **Students' socio-cultural preconditions** (e.g., norms of society, influence of society and life on the student)			

emphasis on improving the way science is taught. There is no doubt that this is essential. However, the Didaktik tradition points out that also the science content itself needs to be seen as "problematic." A content structure *for* instruction needs to be developed that addresses students' learning needs and capabilities as well as the aims of instruction.

Cross-References

- ▶ Bildung
- ▶ Curriculum
- ▶ Curriculum and Values
- ▶ Model of Educational Reconstruction
- ▶ Transposition Didactique

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Digital Resources for Science Education

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How you approach the subject of digital resources in science education depends greatly on how you approach science education. Most science educators try to strike a balance between coverage of domain content, the methods of science investigation to establish that body of knowledge, and the skills needed to understand the first and hopefully engage with the second at some level. Perhaps surprisingly, the epistemology of science – sometimes described as how scientists think – is not always addressed, although school science expectations do typically include a broad category concerning the nature of science. At the school level this is commonly reduced to a description of science as a cycle of observation, deduction and testing, though this represents only one form of scientific inquiry, modelled on Baconian principles, and excludes the range of other valid methods used to gather evidence and build knowledge in science. The issues of how we think about science and how we treat the nature of science within science education are dealt with elsewhere in this encyclopedia. However, it is important to hold in mind when reading this entry that how you employ any digital resource, including the learning context and task built around that use, is as significant as the nature of the resource itself.

The range of resources available can support and enrich a wide range of inquiry approaches, as well as more didactic approaches to science teaching. In any classroom there is likely to be a mix of these approaches, with the balance determined by a range of factors including the curriculum and assessment regimes in place and teacher preference. Rather than attempt a comprehensive list of actual sources, which would soon date, the table below summarizes the commonly used types of digital resource in terms of the activities in which they are typically applied and the main affordances they offer.

Activity	Resources	Affordances
Researching/ learning about a topic	Web sites, tutorial programs	Wide range of content available via the Web, structured and interactive presentation to give feedback on learning
Creating an argument	Argumentation environments	Supporting the development of an evidence-based rationale
Developing a model or concept map	Concept mapping tools, argumentation tools	Creating links and building a representation of relationships between concepts
Planning an investigation	Word processing	Writing and editing are tools to aid thinking and improve a plan
Inquiry projects	Scaffolded inquiry learning environments, e.g. Webquests	Carrying out an inquiry-based activity in a supported virtual environment
Investigate a model	Modelling environments	Building and/or experimenting with representations of complex systems
Taking measurements	Data logging and virtual experiments/ models	Ability to collect more data, run more iterations, and capture events too slow or fast for traditional school instruments
Making results tables	Data logging, spreadsheets	Ability to share data and use a class results not just one group
Drawing graphs	Data logging, spreadsheets, databases	Patterns to reveal relationship between variables generated in real time; data can be displayed in a range of ways to achieve most powerful
Doing calculations	Spreadsheets	Ability to work with larger data sets, automate calculation, and investigate relationships
Searching for patterns	Spreadsheets, databases, simulations, modelling programs	Rapid manipulation and larger data sets support an investigative approach to data
Asking "What if?" questions	Simulations, modelling programs	Experimentation can be carried out quickly and easily in simulations and models to prepare for, enhance, or enrich benchwork
Comparing own results with other people's	Social media sites, school learning environment	Larger data sets are more powerful; sharing gives an experience of the social nature of much modern science
Presenting information in a report	Word processing, presentation software	Teachers and students can produce high-quality reports and present these to the class. This process can support students to get feedback on their work and develop their understanding of what they present
Knowledge building	Wiki, knowledge forum, Web 2 tools, online discussion forums	Communicating with peers locally or at a distance, seeking new information and feedback for collaborative knowledge building
Voting or developing social norms	Audience response systems, tagging and voting environments	A particular case of collaborative knowledge building

Digital resources relevant to science learning range from raw, unprocessed data to framework programs which facilitate the management of data, even to the point of building complex simulations of the original systems and processes, and almost all combinations of the two. Whether seeking to present content to be memorized, simulations to support inquiry, or tools to support lab-based experimentation, there are digital resources that can enhance the whole activity or elements of it as shown in the table. Collaboration tools also facilitate the extension of learning beyond the individual, to collaborate with classmates – to compare results or build and test arguments – to connections with learners and experts in online knowledge building fora. Whether the approach is to teach science content or how to think scientifically, or hopefully a mixture of both, there are digital resources to help.

Among the myriad possibilities that digital resources open up for science education is the genuine possibility to join the ranks of scientists who seek out and build new knowledge, not simply to replicate what we already have a solid evidence base to support – important and rewarding though that may be. Perhaps most significant is the opportunity for students to understand the nature of scientific knowledge, that it is built through human endeavor, testable and verifiable, and that even school students can take a crack at it.

The advent of citizen science has seen the growth of Web sites that give students and teachers access to raw data from ongoing scientific research. Perhaps one of the most well known of these has been the Galaxy Zoo project where images captured from fantastically expensive and cutting edge telescopes have been offered to the global population to examine and report on. This is an example of crowd sourcing intelligence. No algorithm can yet match the deductive powers of the human brain to recognize the patterns of a galaxy in an image of a star system, and no science team has the capacity to look at all the images they are capable of capturing. And yet the skills needed to see these patterns can easily be learned – indeed a simple set of questions comparing the image you see to a set of reference diagrams is all you need. And so a situation arises where a school student, with or without the encouragement of a teacher, can become part of a globally significant scientific research project by examining raw data and commenting on it with the very real possibility that they will be the first to sight a new astronomical phenomenon.

Now let us consider how such a resource could be used in a classroom. First, a teacher might use a computer and projector to show a class the Galaxy Zoo Web site, look at a few images, and perhaps show a result of a new sighting made through this project. This could be done in a wide range of curriculum contexts: an example of an astronomical phenomenon in a science topic and an example of the use of the Web in a lesson on digital technology. Alternatively a student may come to school with a presentation she has made based on her experience of working on the site and joining the cohorts of those reporting on new images as part of her project on astronomy. The project may have been spontaneous and her report part of a “show and tell” exercise not even aimed at science. However, an opportunistic teacher might then suggest that all the class look at the site at home, in preparation for a discussion the following week and to contrast this approach to scientific inquiry with the “fair test” model of practical work they are familiar with. There are many options, corresponding to the equally wide range of inquiry approaches and pedagogical designs that may be adopted by science teachers. The resources, however, remain neutral and accessible to many approaches.

Stepping back one stage further from access to raw data or processed digital resources, it is possible for teachers to access scientific instruments so that their students may actually collect data. Although it is unlikely that this will lead to genuinely new discoveries, there is still that possibility, and it certainly gives an authentic sense of the look and feel of working science. The Open Laboratory Web site, launched by the Open University in the UK, in 2013, is one example of access to a range of instruments and simulations of those instruments which students can operate through a computer screen. The site also underscores the notions that many twenty-first-century scientists don't actually work with beakers and test tubes but sit at a computer screen that interfaces with instruments or with massive data sets and complex models built from them and that science is a collaborative activity with many individuals contributing to any breakthrough.

Again, such a resource could be used in many ways with varying levels of control by the teacher or learner, with a learner experience ranging from well defined to open ended. The site could be used to expound certain established areas of content, to explore and discover together or alone, and to experience science as a process or a body of knowledge or any or all of these in combination.

Given that the way the resource is deployed is as important as the nature of the resource in terms of the opportunities it might afford for learning, what then does access to digital resources offer to teachers and learners that transcends the affordances of traditional texts and real-world experiences in the lab or the field? Digital resources offer scale, mutability, and the opportunity to share, revise, and store. Instead of looking at a static data set (e.g., in a table form) or image, it is possible to access many examples, dynamically, comparing and contrasting, looking for patterns, and even gaining an understanding of the variation. For example, when teaching the topic of sound, it can be difficult to make a link between the frequency of a note and its representation on a musical scale. This is not a common approach in textbooks, yet a Web search will quickly unearth a range of descriptions of this relationship that help to build a link across the subjects of physics and music. It will include simulations and animations that help to bring descriptions to life. Once these various sources have been gathered, it is possible to capture elements, add a personal explanation, and make a presentation that explains the phenomenon to yourself (using appropriate citation!) and then to share this with a fellow learner or teacher. Feedback and comments from peers or teacher can then help the student to refine the accuracy and clarity of the end product. Finally, the end result could be shared or simply stored for later review and revision, either for a test or to integrate into further understandings or inquiries into the topic – perhaps in a music class or in a later science course. This example is theoretically possible without digital resources, but in practice could not be achieved easily, or to any level of scale. The essence of digital resources is that they make it realistic to teach and learn in ways that support genuine personal knowledge building rather than rote learning.

There are a few caveats to the use of digital resources in science education. Perhaps most important is that there is a great risk of replacing hands-on, sensory experience with digital alternatives. Just as playing a snowboarding simulation game will never result in one's learning how to snowboard, nor will it ever replace the experience of actually swishing down a mountain, manipulating simulations will never entirely replace scientific lab or fieldwork. Used well, however, such experiences can extend and enhance the student's inquiry into scientific topics. Also, there is a vital element of feedback entailed when a student works to create personal digital records: such products of inquiry must be personal, not simply cut and pasted with little thought, editing, or original commentary. Finally, there remains a gap between the theoretically possible and the achievable when it comes to supplying access to digital resources for students. Having a class of 30 access high-definition video on personal devices over a wireless network is likely to be problematic. So, careful planning and judicious use of resources both in and out of the school environment are required if any of the above scenarios are to be achieved through meaningful hands-on experience for all students rather than teacher demonstration.

Cross-References

- ▶ Argumentation Environments
- ▶ Blogs for Learning
- ▶ Concept Mapping
- ▶ Modeling Environments
- ▶ Models
- ▶ Simulation Environments
- ▶ Wikis

Dilemmas of Science Teaching

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Keywords

Classroom management; Teaching dilemmas

The term *dilemma* is derived from the Greek (via Latin) terms di meaning two and lemma meaning assumption or proposition. A dilemma is a situation that requires a choice between two options that are, or seem, equally unfavorable or mutually exclusive, hence, the expression, "caught on the horns of a dilemma" – when opting for one choice over another, one is stuck uncomfortably on the horn of that choice and unable to do anything about the alternative option.

In educational contexts, the dilemma idea was explored in Berlak and Berlak's (1981) book *Dilemmas of Schooling*. Here, the authors examine how numerous curriculum and societal dilemmas impact on schooling. These include child as person vs. child as client, content vs. process, knowledge as given vs. problematical knowledge, learning as social vs. learning as individual, common culture vs. subgroup consciousness, equal vs. differential distribution of resources, and equal vs. ad hoc justice. The authors contend that the dilemma language can assist teachers to be critically aware of the consequences of these opposing dispositions and to develop patterns of resolution. They discuss an example of the control dilemma (whole class vs. individual) where a teacher is dealing with inattentive boys during reading time. She intervenes more frequently with the boys than she does with the girls, perhaps indicating an assumption that boys need more control than girls. The authors suggest that this dilemma could be resolved by employing any number of alternative teaching strategies, including differentiated reading materials for boys and girls, or giving both boys and girls more responsibility for choosing their reading matter.

Another take on dilemmas in teaching was presented by Lampert (1985), who paints a picture of the teacher as a dilemma manager. In one of her cases, Lampert describes a grade 4 lesson on the water cycle. One of the students in the case declares that water comes from the ocean, whereas the textbook answer indicates that water comes from clouds. In moderating a class discussion about which is the correct answer, the teacher avoids the dilemma trap by accepting that both answers are correct. In her analysis of this and other cases, Lampert rejects the notion of teacher as a "technical-production manager who has the responsibility for monitoring the efficiency with which learning is being accomplished" (p. 191, original emphasis). Rather, she sees the teacher as a dilemma manager, "an active negotiator, a broker of sorts, balancing a variety of interests that need to be satisfied in classrooms" (p. 190).

In their 2002 edited book, *Dilemmas of Science Teaching*, Wallace and Louden present a series of science teaching dilemmas through teacher-written cases. Accompanying each case is a set of commentaries by distinguished science education scholars and a synthesis by the editors. The cases present a range of dilemmas faced by science teachers, about science itself, about difference, about representation, and about teaching and learning. Three examples from the book illustrate the way in which dilemmas are played out in the science classroom.

The first case, entitled *To tell or not to tell*, involves the dilemma faced by a teacher who wants to encourage students to explore their naïve understandings of science (in this case electrical flow). At the same time, he finds that their understandings fall short of a robust scientific explanation of the phenomenon. According to Wallace and Louden, at the heart of this dilemma is the issue of who has responsibility for learning. "In order to move beyond a reliance on the teacher for the right answer, there is a need for students to accept some responsibility for learning.... Good teachers tread "the 'middle ground' on this issue mediating between the two extremes of telling (and therefore taking on some of the responsibility) and not telling (and encouraging students to take more responsibility)” (p. 203).

The second case involves the use of analogies in science teaching. The teacher in the case described the difficulties she encountered when she used the analogy of a city to explain the structure and functioning of a cell. The teacher found that because students had different understandings and experiences of a city, the analogy was useful to some and unhelpful to others. Moreover, the phenomenon (the cell) comes in different shapes and sizes. The dilemma for the teacher was how far should she push the city analogy before it becomes self-defeating. As the authors point out, managing this dilemma involves a two-pronged strategy of probing into students’ experiences to increase their understanding of the analog *and* helping students understand how analogies are used in science to explain complex and variable phenomena.

In the third case, the authors examine the different responses of girls and boys in activities designed to explore series and parallel circuits. The boys quickly helped themselves to the equipment and adventurously experimented with different arrangements of batteries, wires, and bulbs. The girls were more cautious and soon found themselves falling behind, requiring direct help from the teacher. As Wallace and Louden put it, “The subject matter, the opportunities to compete for resources, the teacher’s different responses to the boys vs. the girls all point towards ‘boy-’ rather than ‘girl-friendly’ science” (p. 84). The teacher is caught in the middle of this dilemma, whether to focus the lesson more on girls’ experiences or boys. Managing this dilemma means attention to both realities, to enable girls as well as boys the opportunity to expand and explore their different experiences and understandings.

To summarize, science teaching is an activity rich with dilemmas. Teachers are required to balance many competing educational demands, for example, between attending to the individual and the rest of the class, between respecting students’ naïve understandings and promoting canonical knowledge, between listening and telling them the answer, and so on. The best science teachers are those who manage their way through these apparently irreconcilable differences with diligence, good humor, and respect for all those involved in the teaching and learning process.

Cross-References

- ▶ Classroom Organization
- ▶ Pedagogical Knowledge

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Discourse in Science Learning

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Keywords

Conversational analysis; Ethnography of communication; Sociolinguistics

Discourse practices and science learning

Discourse is the use of language in context. In each instance of use, discourse is constructed among people in some context, with some history, projections of future actions, and ideological commitments. As discourse entails more than the ideational communication, the broader contexts of social groups, cultural practices, and interpersonal goals need to be taken into consideration when deciphering meaning in interactional contexts. Social norms, expectations, and practices are constructed through discourse processes and, in turn, shape ways that discourse is evoked in each instance, thus instantiating the symbiotic relationship of discourse and sociocultural practices.

Discourse is central to the ways communities collectively construct norms and expectations, define common knowledge for the group, build affiliation, frame knowledge made available, provide access to disciplinary knowledge, and invite or limit participation. Such communicative processes are central to education. The ways that teachers and students use discourse in educational events have bearing on how learning opportunities are supported or constrained. In science classrooms the ways that teacher talk science, frame communicative norms, and engage students in the range of semiotics of the relevant discipline construct the nature of the scientific knowledge and practices available to be learned (Kelly 2007). Studies of student learning suggest that features of scientific discourse are not mastered as received knowledge through didactic instruction, but rather through participation as a member of a group in a discourse community. Students learn meanings of scientific terms through engagement in discourse and practices.

Scientific discourse includes some unique features, derived from the highly specialized nature of the epistemic communities constructing these discourse processes and practices. In professional and educational settings, scientific discourse is characterized by multiple modes of semiotic communication, including spoken, written, representational, inscriptional, and symbolic, among others. The range of semiotic communicative forms shows wide variation and is often alien to science students' ways communicating in others aspects of their lives. This may pose challenges to learners of science, as the unique linguistic forms of science including the use of passive voice and conditionals, technical vocabulary, interlocking taxonomies, abstraction and nominalization, and complex symbols and notational systems (Halliday and Martin 1993). Studies of classroom discourse have documented ways that it is common for science to be constructed through talk and action in ways often alienating to students, leaving the impression that science is difficult, reserved for cognitive elites, and regimented (Lemke 1990).

A central concern for science educators has been student access to scientific knowledge. Discourse studies have contributed by identifying differences between scientific discourse and students' everyday ways of speaking, knowing, and being in other settings. This concern for equity in science learning has led to studies of the ways that scientific concepts are constructed. In particular, the importance of uses of metaphors and analogies has been identified as a key component to the development of student understanding. Furthermore, there is evidence the variation of students' home discourse with that of science is an important impediment to learning. Students from language backgrounds, often falling along class, race, and ethnic lines, that differ from that spoken by scientist and science teachers face more serious learning challenges than students whose discourse background matches that of science teachers. Taking on a scientific discourse includes building an identity with the discipline and members of the local discourse community, which can be alienating for some students. Thus, studies of educational equity need to account for language variation, specific forms of scientific discourse that pose problems for learners, and ways that affiliation and identity are constructed through language use.

The study of discourse has also been viewed as important for student engagement, including inquiry approaches and student-led group work in laboratory settings. Inquiry teaching often involves students in scientific practices using language such as posing questions, providing explanations, communicating results, evaluating inferences, and critiquing ideas. As these practices are heavily language dependent, discourse analysis provides a way to consider how opportunities for learning are constructed in education events and how the merits of educational practice can be accessed. Inquiry instruction often includes students working with material objects to derive conclusions based on evidence. The processes of discovering how to make inferences, draw conclusions, and communicate results are interactionally accomplished through discourse. Thus, student reasoning can be viewed as a social process, highly dependent on the types of discourse moves available in their sociolinguistic repertoire.

One central practice emerging as relevant to many pedagogical approaches is argumentation. Argumentation refers to the uses of evidence to persuade an audience of the merits of a position. This is particularly relevant to inquiry approaches that place emphasis on evidence and explanation. Building an argument entails understanding the genre conventions for ways of aligning data, warrants, and claims. Furthermore, argumentation is often employed in interactive settings where students are able to make support and defend claims against criticism and counterclaims. Discourse includes the uses of signs and symbols, important for communicating and critiquing scientific models, graphs, and other knowledge representations. Argumentation is thus a learned discourse practice, with particular genre conventions that come to determine what counts as relevant data, a valid argument, sufficient evidence, and so forth.

Learning to teach and learning from teaching involve understanding how to employ, decipher, interpret, and produce discourse in the moment-to-moment interactions of educational events. Teacher education has become increasingly focused on the ways that science teachers learn to reflect on their practice and in particular how to use discourse moves to engage students in reasoning about ideas. As science education reform has increasingly focused on ways to help students understand concepts, models, and epistemic practices, teachers face the challenges of helping students engage with the subject matter in these ways.

Across the range of substantive topics of research and in various educational settings, a number of communicative issues have been observed. Often discussion in science classrooms is directed by teacher talk, following closely science textbooks. Such talk in the interactional context of whole-class discussion falls into a pattern of teacher initiation, student response, and teacher evaluation (IRE). This pattern of talk has implications for what is made available to learn, how the particular science discipline is positioned, and how students develop their identity with science. Yet, educational reformers have argued for a more expansive range of interactional contexts that include opportunities for an active role of students in classroom conversations. Mortimer and Scott (2003) propose a model to examine five important dimensions of classroom discourse: teaching purpose, science content, communicative approach, patterns of discourse, and teacher interventions. This model helps understand the nature of discourse events and provides a basis for designing teacher education with a focus on the centrality of discourse for science learning.

Discourse analysis refers to the study of language in use. To examine the range and types of communicative situations of discourse in science education, analysts have sought to understand how uses of discourse are situated in social practice and over time. Social practices, norms for interacting, and expectations about communicative demands are tied to the ways that language is used. Discourse analysis thus often considers how talk and action is shaped by the norms and expectations of the communicative events. This suggests the need for ethnographic and other research approaches that seek to understand broader cultural patterns of activity governing the uses of discourse. Such studies consider the micro-moments of interaction, the meso-level construction of practices through multiple interactions, and the macro-level analysis of cultural practices. Spoken communication occurs through both verbal and nonverbal channels. To understand meaning in interactional contexts, discourse analysis needs to consider pitch, stress, intonation, pause structures, physical orientation, proxemic distance, and eye gaze, among other paralinguistic features of talk.

The conceptual and epistemic goals of science education entail developing the linguistic repertoire of students. The perspective of discourse analysts suggests that learning concepts means being able to communicate with members of a group in an effective manner. As students come to learn science concepts and engage in scientific practices, they develop more expansive ways of speaking, listening, and interpreting the discourse of science and can be viewed as communicatively competent with members of a relevant community (e.g., other science students, scientists in a particular discipline, member of a community activist group focused on environmental issues). Thus, effective uses of discourse enhances student learning by expanding the range of their repertoire to communicate and learn from others. Such a view is consistent with sociohistorical learning theories that consider cultural tools, signs, and symbols that mediate social interaction as a basis for learning (Vygotsky 1978).

The implications for science teaching of discourse studies in science education are clear. As engaging with science includes working in a range of semiotic fields, teachers need to find ways that students are given opportunities to use words, signs, and symbols to communicate and interpret meaning in a variety of interactional contexts and settings. By providing opportunities for students to learn through speaking, listening, and using concepts in context of use, i.e., while engaging in scientific practices such as observing, reasoning, explaining, or providing evidence in an argument, teachers can engage students in science through active participation where learning is most likely to occur.

Cross-References

- ▶ Activity Theory and Science Learning
- ▶ Argumentation
- ▶ Discussion and Science Learning
- ▶ Socio-Cultural Perspectives and Characteristics
- ▶ Sociology of Science

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Discovery Learning

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“Discovery learning” is a label that has been prominent in discussions about education, including science education, since at least the 1940s.

Like all popular terms in education, discovery learning has taken on a range of meanings, but most often it refers to a form of curriculum in which students are exposed to particular questions and experiences in such a way that they “discover” for themselves the intended concepts. The student’s inquiry is usually “guided” by the teacher and the materials, for example, through “Socratic” questions, because no one expects them to arrive on their own at ideas it took scientists centuries to develop.

Many scholars, including the authors of this entry and the editors of this encyclopedia, see the term as having little value today. This is in part because some proponents of “discovery learning” make extreme claims for the benefits they see in student discovery of concepts and in part because the term has become rather debased by its highly inconsistent use in a range of educational debates (including as a pejorative term) (Hammer 1997).

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Discovery Science

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Keywords

Computational science; Data-intensive science; Information literacy; Scientific computing

Technological advances over the last several decades have disrupted the very nature of our day-to-day lives, as well as scientific research. Grand challenges facing society drive research and education to address questions that require intensive computation and data analysis. Such grand challenges include:

- What is the impact of global and regional climate changes?
- Can carbon dioxide be safely sequestered to minimize the release of greenhouse gases?
- How can we better predict and plan for natural disasters (earthquakes, tsunamis, wildfires, avalanches)?
- How can breakthroughs in genetics be used to cure/fight cancer and other diseases?
- What is the structure of the Milky Way galaxy?

As a result new paradigms of science have emerged. The **empirical method**, the application of experimental data to predict and describe natural phenomena, arrived on the scene 3,000–4,000 years ago and was evident in the lists of Pythagorean triples in Babylonia; in an Egyptian medical textbook (circa 1600 BC) that applies examination, diagnosis, treatment, and prognosis to the treatment of disease; and in charts of planetary motion. The Age of Reason (1400–1700 AD) brought the birth of **theory**: science based on principles that are developed through the use of models and generalizations. Theory was manifest in Galileo's studies of motion; the writings of Hailey, Kepler, Pascal, and Huygens on planetary motion; the development of calculus to explain mechanics by Newton and Leibniz; and Napier's formulization of logarithms. (See *The Fourth Paradigm*: *Data Intensive Scientific Discovery* (Heyet al. 2009) for a detailed discussion of this history.) Until recently, the empirical method and theory were considered the two legs of science. Over the last 20 years, with the advent of powerful computing capabilities, two new science paradigms have arisen: computational science (scientific computing) and data-intensive science (data-centric science).

Computational Science or Scientific Computing

Scientific computing has emerged as the third leg of science, joining theory and experiment. It allows us to attack previously unsolvable problems and make transformational advances in science and engineering to address global challenges in energy, environment, and national security (Wadsworth 2006).

Scientific computing is not computer science per se. Computer science develops technological hardware and software and is a discipline unto itself. Scientific computing is the use of the hardware and software to guide the discovery of new science. Scientific computing is embedded in mathematics, science, and the humanities; it complements experiment and theory, but does not replace them. As others have put it:

> It is both the microscope and telescope of modern science. It enables scientists to model molecules in exquisite detail to learn the secrets of chemical reactions, to look into the future to forecast the weather, and to look back to a distant time at a young universe. (Fosdick et al. 1996)
>
> Scientific computing focuses on simulations and modeling to provide both qualitative and quantitative insights into complex systems and phenomena that would be too expensive, dangerous, or even impossible to study by direct experimentation or theoretical methods. (Turner et al. 2011)

Examples of the use of scientific computing include the study of wind turbines, oil and gas recovery, CO_2 sequestration, seismology, hydrogeology, cloud formation, carbon and water cycles, wildfires, and genetic adaptation.

Data-Intensive Science

The explosive use of personal data, new data collection technologies, and the capabilities and speeds of modern personal and supercomputers has resulted in a wealth of information and data. Simulations of complex models are generated on a 24/7/365 basis and involve multiple scales. The outcome has been the invention of data-intensive science as a fourth paradigm, which has four main activities:

- Capture: How can sensor networks be used to capture geological or ecological data? How can nanotechnology devices be used to gather biomedical data at the individual level?
- Curation: Where and how do we store the data to make it useable?
- Analysis and modeling: How do we mine (i.e., extract useful information) from the data? How can we make inferences without seeing all the data? Can we make models that explain the data?
- Visualization: How does one fully comprehend large data sets? How can we make the human-computer interface more effective?

Computational Science Example

Given these two new paradigms of science, it is important that K-12 educators provide their students with the basic underpinnings of scientific computing and data-intensive science. Let's explore a very simple example to illustrate scientific computing and how technology can give students earlier access to scientific topics than through theory and experimentation alone. The example concerns modeling heat diffusion on a plate using a freely available software package NetLogo. The NetLogo model allows the user to select the plate's material and the temperature conditions on the plate's boundary and then model the diffusion of heat on a plate over time. This allows the user to simulate multiple iterations of the model without knowledge of the heat equation which utilizes partial differential equations (Fig. 1).

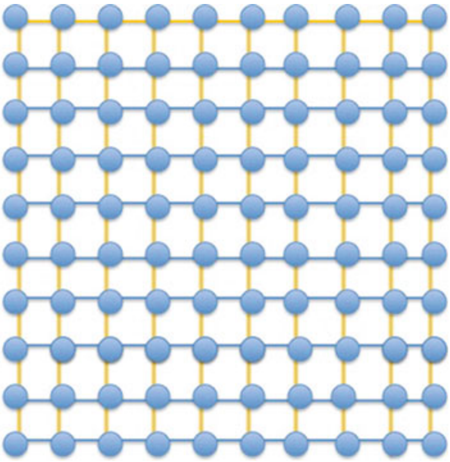
By reducing the example into a discrete model where the plate is represented by a 10 × 10 square (Fig. 1), the concept of heat transfer can be simplified to the level of elementary arithmetic: calculate the average temperature differences around a given node to determine the new temperature of that node. A particle's temperature changes at a rate proportional to the difference between its temperature and the average temperature of its neighbors. For example, if a point P has temperature of 12°, with neighboring points of temperatures 10°, 10°, 20°, and 20°, and the constant of proportionality for heat transfer is 1/3, then point P will have an updated temperature of $12 + 1/3((-2-2+8+8)/4) = 12 + 1/3(3) = 13$. In the 10 × 10 model, finding the new temperature at each point is a matter of four subtractions to determine temperature difference and four additions and two divisions to determine a new temperature, a process that can be completed by hand. However, in a 100 × 100 square, there are 100,000 required calculations per step, and while each step is simple, the number of calculations requires a computer simulation. If we make the grid 1,000 × 1,000 units, the computation requires 100 more calculations per step taking the total number of calculations up to ten million. Expanding this to three dimensions, a cube 1,000 units on each side, requires ten billion operations to calculate the temperature at each node. The necessity of high-performance computers for simulations for even the three-dimensional model is clear.

Education Issues

There are four key elements of why such models are important to student understanding:

1. The dynamic, visual nature of such models
2. The allowance of easy variation of parameters
3. Forced construction of equations out of physical observations
4. Opportunities for a better understanding of orders of magnitude

Computational thinking integrates the power of human thinking with the capabilities of computational processes and technologies. The essence of computational thinking is the generalization of



Discovery Science, Fig. 1 Partial differential equations governing heat transfer on a plate

$$\frac{\partial T}{\partial t} = k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) = k\Delta T$$

$T(x,y,t)$ is the temperature of the point (x,y) at time t,

k is a constant, and

Δ is the Laplacian operator.

ideas into algorithms to model and solve problems. The new paradigm of scientific computing impacts teaching in four distinct ways:

1. Profoundly – never before have two new paradigms occurred within such a short time frame, and we need to think of scientific computing as a fundamental twenty-first-century skill (Wing 2008).
2. Systemically – not as a separate subject area, but as a paradigm relating the interdisciplinary nature of science, engineering, and the humanities. Scientific computing has a symbiotic relationship with mathematics, science, and engineering; computational thinking requires abstraction and the ability to work with multi-layered and interconnected abstractions (e.g., graphs, colors, time); and it draws on "real-world" problems.
3. Vertically – scientific computing must be developed over many years (Pre-K through college) with a need for experiences to be provided early. Examples of vertical strands are provided in Table 1.
4. Wisely – programming should be incorporated at appropriate times. Computational thinking is not just programming or computer engineering; and much of computational thinking can be developed without programming. The emphasis should be on quality, not quantity of experiences, and the experiences must be tied to the thought processes that arise in utilizing a computer to model a system or mine a data set.

Data-intensive science should also inform our teaching. There is a need to provide basic information literacy skills so that students can be productive members of the twenty-first-century workforce and adapt to an increasingly data-dominant world. Teaching should address the following: How is data mining done? How are inferences drawn from large data sets? What are the pros/cons of models? How can one digest data? Teachers need to make learning more authentic. There are a wealth of resources to connect content areas to "real-world" problems. Curriculum needs to have more depth, less breadth. Project-based and place-based learning pedagogies provide a framework for moving toward in-depth learning experiences for students. We need to change the way we "see" and sense data. This can be done by providing student experiences with multiple interpretations and representations, such as 3D, color graphics, and different scales. Interdisciplinary understandings will be essential, since real-world grand challenges must be approached from multiple perspectives. This calls for more integrated curricula that move away from the silo effect where disciplines in schools are isolated from each other. We must help develop new intellectual tools and learning strategies in our students, such as comprehension of the importance of different scales, the understanding of complex systems, and how does one frame and ask meaningful questions, We also need to provide new experiences for the students

Discovery Science, Table 1 Vertical strands of scientific computing (for more details, see http://www.iste.org/learn/computational-thinking/computational-thinking_toolkit.aspx)

Components	Examples
Algorithms	Importance and qualities of algorithms, binary vs. linear search, finding averages independently and in parallel, basic computational algorithms and their efficiency
Modeling	How we get mathematical observations, addition as counting and multiplication as area or repeated addition, graphs as ways to see change, hands-on dynamical systems, relating physical laws to equations, relating change to slopes of graphs, studying complex, multi-agent phenomena
Probability	Understanding of randomness; basic probability concepts; meaning of average behavior, trends; law of large numbers; geometric probability; sampling through random walks; quantification of uncertainty in simulations (use of ensembles)
Decomposition	Breaking down a task or process, doubling methods to multiply, areas via simple geometric subdivisions, steps for solving different types of equations, areas via integration
Complexity	Understanding of interrelationships and complexity, basic cause and effect, sum of parts can be greater than whole, interpretation of graphs, multiple variable interrelationships
Pattern recognition	Multiples, divisibility, triangular numbers, linear-area-volume dynamic change
Abstraction	Pattern generalization, ability to filter out information, ability to generate information needed, making and verifying conjectures, variables

including collecting and interpreting data from sensors, mining data, collaboration in framing and solving problems, conducting interdisciplinary synthesis, using science to inform policy inferences, use of scientific computing, use of data gathering tools, and practice in visualization. Finally, students must be exposed to statistics, with a focus on data-driven problems and understanding statistical concepts.

Cross-References

- ▶ Authentic Science
- ▶ Futures Thinking in Science Education
- ▶ Integrated Science
- ▶ Models
- ▶ Problem-Based Learning (PBL)
- ▶ Representations in Science
- ▶ Science, Technology, Engineering, and Maths (STEM)
- ▶ Transformative Science Education

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Discussion and Science Learning

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In memory of Phil Scott

Keywords

Dialogue; Discussion; Exploratory; Interthinking

Learning about science involves asking questions about the world around us and collecting evidence that will help to answer them and then asking further questions. Establishing a theory in science involves people systematically testing their own and other people's ideas to develop robust explanations which fit the evidence. In science, there is never really definitive proof as we might find in mathematics but a gradual working towards a more robust scientific point of view that can explain observations, data, or other evidence. Science learning begins as children question things naturally and draw conclusions from their lived experience. So, a child kicks a ball and notes that it slows as it rolls along the grass and then stops. A reasonable hypothesis for this observation is that the energy put into kicking the ball has been used up. A ball rolling down a hill does not need as much energy because it is easier to go down than up. Similarly a child might notice that the sun is behind nearby trees in the morning, but by lunchtime it is overhead, and that sometimes the sun is yellow, sometimes red. The sun must therefore both move and change color. The use of metaphor, imagery, and imagination in some of our common ways of describing natural phenomena also offers learners a kind of explanation for how things work: for example, "darkness fell," "waves bring the tide up to the top of the shore," "the toy won't work because the battery has run out of electricity."

The outcome of making meaning from a mix of everyday observation and language experiences is that children generate for themselves some work-a-day explanations of the natural world. Such explanations – which may never be articulated – seem to fit what is observed and can last a lifetime. However, assiduous generations of scientists have collected enough information for us to be able to identify some of these ideas as "misconceptions." A ball rolls to a halt under the influence of friction and gravity. Energy cannot be used up. The sun stays in one place while the earth spins; its color is affected by the atmosphere that light passes through to reach us. Batteries contain not electricity but chemicals which can generate electricity. Learning in science must therefore involve eliciting children's already-formed ideas, then providing a range of experience and evidence to help the child to see a different and more scientific perspective if necessary. To consolidate learning, we can enable a child to apply their new knowledge in ways that help them to understand that it is sound and generalizable.

The body of established scientific knowledge, carefully accumulated over the years, is important to us and to the well-being of the earth. It is unnecessary for each child or each generation to repeat the process of finding everything out from scratch. And so an effective education in science involves an intricate mix of activity, discussion, and practical application, including helping children to understand and acquire the relevant skills and the processes scientists go through to ensure that their investigations can be replicated. It involves children in learning both what is established as factual knowledge and the technical language which helps scientists to communicate accurately and concisely with one another. As Jay Lemke puts it, children must become "fluent speakers of science." Science learning necessitates acquiring a collaborative approach and developing the capability to analyze, communicate, and formulate testable questions.

There may be famous scientists who have made strides in establishing science concepts alone; but mostly it is cooperation, discussion, and thinking together that create new ideas. Science is not just factual information and enquiry but also a set of attitudes and values to do with accepting responsibility, being aware of implications of research, and staying open-minded. Einstein, at first completely dismissive of the idea of a Big Bang starting the universe, later gracefully conceded that Hubble's work showed that this was so. Finally, for the teacher, science learning also involves keeping alive the quirky capacity for curiosity and creativity that helps scientists to make the little leaps of imagination – or the seismic shifts – that keep moving human knowledge onwards.

Discussion in Science Learning

Two seminal UK projects in science education of great international influence were the Children's

Learning in Science project (CLIS; University of Leeds) and the Science Processes and Concept Exploration project (SPACE; King's College London and University of Liverpool). The SPACE approach was to "start where the children are," building on the ideas children bring with them to lessons and helping them to develop their understanding of scientific concepts. The CLIS approach involved activity and reflection in which science concepts were tried, tested, and discussed through an imaginative practical approach. Indeed both projects involved science as a practical subject and foregrounded the role of teachers in engaging, motivating, and stimulating the curiosity of children while providing them with a solidly scientific perspective on the world around us. Both have left a valuable legacy of theory and practice for science teachers. In addition another UK project, the CASE (Cognitive Acceleration through Science Exploration) project (King's College, London), was built on a teaching approach involving metacognition, that is, children's reflection on their own thinking. This has been shown to have a marked impact on cognitive development and academic achievement. Primary science education in the UK was given a boost with the introduction of the National Curriculum in 1995 when it was established as a core subject and allocated equal time with English and mathematics. Subsequent revisions of this curriculum have meant that schools have allocated more priority to English and mathematics, at the expense of other subjects. The 2014 National Curriculum highlights the importance of teaching a scientific understanding for our children and strongly suggests that teaching strategies should involve discussion which enables children to ask their questions and talk through tentative ideas.

Both primary and secondary science classrooms in many parts of the world have in the past been characterized by their quietness; teachers were often evaluated by the noise level of their classrooms, silence being highly rated and children's talk being frowned upon. However, the influence of a sociocultural approach to learning has led teachers, particularly primary teachers, to feel that it is quietness that should cause unease rather than noise, at least if it is the dominant mode of the classroom. Learning is today understood to be social. The child's first and best means of communication is through spoken language. The Russian psychologist Lev Vygotsky and the translators and interpreters of his work have helped educators to feel confident that encouraging children to talk in class is of great benefit to their learning. Vygotsky noted that language offers tools with which ideas can be shaped and articulated, then offered for joint reflection. Once aired, ideas can become part of the shared understanding of a group, available for discussion and modification. Being part of a group talking about ideas in science allows individuals to internalize ideas, reflect on them, and bring their modified thoughts to subsequent discussion. Jerome Bruner realized that children in a classroom can be one another's best resource if they can communicate their thoughts through such discussion. Talk offers the chance to share understandings of scientific phenomena and come to a larger consensus or a productive disagreement. Either such consensus or disagreement can help to establish a robust theory or a new line of enquiry.

In his extensive listening to students talking in groups, the educational researcher Douglas Barnes noted that spoken language enables the individual, and the group, to begin to organize ideas. Talk may be hesitant as ideas are proffered and considered; contributions may be incomplete and tentative. Barnes saw that what he termed "exploratory talk" was of great value in aiding understanding and allowed children to express knowledge, opinion, and uncertainty. Importantly, he recognized that if groups of children were to achieve such effective discussion, their talk together must be of a specific quality, a different type of talk than their usual more casual interaction with one another, and so raising their awareness of discussion as a tool for learning would mean that group work became more reliable and effective. He identified a type of talk in which children tentatively try out their own ideas in comparison with the views of others. He suggested that children should be encouraged to contribute ideas from their own experience and to suggest where there seemed to be discrepancy between points of view. In addition, Barnes advocated encouraging children to ask productive questions and noted that it would be invaluable if students were taught how to elaborate on their initial ideas. Discussion in science classrooms should draw on these ideas to ensure that science teaching is inclusive, starts with the child, and develops both science knowledge and understanding.

Every child can communicate, and almost all have a range of talk repertoires at their disposal. Children switch between talking in a range of contexts such as the playground, at home, during competitive sport, in class, and so on. They can also talk to adults appropriately and are able to use their individual accents and dialects to communicate fluently. Each of these types of talk is of equal value as the child functions in their social world. Each type of talk, including classroom science discussion, is based on some implicit, straightforward, but essential "ground rules." Ground rules are the usually hidden ways that people devise to organize themselves so that social harmony is possible. Ground rules for discussion in class are different from the ground rules, for example, of playground talk, talk between children and their parents, or talk between children playing a collaborative game.

Neil Mercer and Rupert Wegerif, in studying children talking about science at computers, found that some children were unaware of the ground rules for exploratory talk. Group work ended in disharmony, and learning fell away as disputes arose which could not be resolved, or groups simply agreed with initial suggestions and did not seek understanding. It was apparent that some children had no experience of a reasoned, exploratory discussion. In learning terms, this is analogous to only having heard traditional stories and never having experienced science fiction, or a ghost story, or a mystery story. It is simply a gap in experience which can be addressed by teaching. Other children were aware of the ground rules which could help them to think and learn together but were unable to apply them. Still others felt that sharing their knowledge and understanding would diminish their personal status – everyone would "know" as much as they did. The ground rules for exploratory talk as later elaborated by Neil Mercer can be summarized as listen to and include everyone, ask questions, challenge what you hear, give explanations with reasons and elaborate on your ideas, and seek to reach a negotiated agreement. The discussion, creation, and use of a class set of "ground rules for exploratory talk" helped children to see that sharing learning does not make individuals poorer but makes the group richer and that exploratory talk could help everyone to articulate their ideas and could help individuals, groups, and the class to establish a joint, robust scientific point of view.

Substantial work elaborated in a number of other entries in this encyclopedia has been able to provide examples which better establish Vygotsky's ideas, left as hypothetical by his untimely death, and thus contributed to educational theory in science learning. For example, Vygotsky saw individual thought as a product of reflection; spoken language he describes as allowing intermental ("between minds") thinking and drawing on intramental ("within the mind") or individual thought. He postulated that adults talking to children in an exploratory way – though he didn't use that term – would be able to influence their thinking. That is, intermental thinking influences intramental thinking; but crucially, that subsequent talk could draw on the newly developed thinking of individuals, contributing to the group's subsequent better understanding. Discussion like this, Vygotsky argued, creates a spiral of learning, as individual development supports group thinking which in turn aids individual understanding and so on. This spiral has been observed, for example, in samples of children's talk about science collected in the Thinking Together project, so confirming Vygotsky's hypothesis. For science learning, this means that children, engaged in a combination of science activity and discussion based on exploratory talk, can learn from and with one another and can construct new knowledge together in a way that is accessible to all of them.

In addition, by engaging in exploratory talk in science, children are learning in effect "how to discuss." They become more adept at listening actively, asking pertinent questions, providing reasons for their contributions, weighing up and summarizing what has been said, and coming to an agreement together or establishing new questions together. This is a transferrable skill and is the basis for rationality, teamwork, and social learning. Neil Mercer has described the joint reflection generated when members of a group engage one another in exploratory talk as "interthinking." Interthinking is a powerful way for groups to proceed during enquiry, problem solving, and understanding new ideas not only in science but across the curriculum. Science learning in classrooms therefore requires carefully organized group work based on the direct teaching of the skills of exploratory talk, the establishment of relevant ground rules for discussion, and in helping children to see how and why to engage in interthinking.

Dialogic Teaching in Science

Relevant science learning involves the teacher enabling children's access to current scientific thinking. Traditionally this has involved such strategies as chalk-and-talk and the completion of "worksheets." More recently the idea of "dialogic teaching" has described how science teachers can engage children in whole-class debate about their ideas in science. Dialogic teaching as described by Robin Alexander involves teacher and class in a searching, cumulative debate, orchestrated by the teacher. During dialogic teaching, children take extended turns, explaining what they know or do not know, and responses are chained together in a meaningful way, stimulating further contributions. It is worth noting that there are clear links between the spoken language structures of dialogic teaching and those of exploratory talk, that is, teachers who generate dialogue are teaching children how to talk effectively to one another in groups.

A distinctive feature of dialogic teaching is that it involves teachers asking authentic questions (as opposed to the common classroom practice in which teachers ask questions to which they already know the answer, in order to involve children or to check knowledge items, for example, *Teacher*: What do we call the ends of magnets? *Child*: Poles. *Teacher*: Yes, that's right).

In dialogic teaching, answers are much less predictable and less likely to be a single word, and any child can answer, not just those who choose to put up their hand. The teacher keeps the discussion open. If the above example of closed and conventional questioning is recast as it would be in dialogic teaching, it would be something like the following:

> *Teacher*: What sort of magnets do you think are strongest?
>
> *Child*: My brother has some you throw up in the air, and they stick and make a funny noise.
>
> *Child 2*: The horseshoe magnet, the red one, it's big, but it's rubbish with the paper clips.
>
> *Teacher*: Anyone else with information about horseshoe magnets?
>
> *Child 3*: The ends both pull together, they – it doesn't mean it's strong, you even get them at playgroup.

In elaborating the idea of dialogic teaching, Phil Scott established that learning in science classrooms proceeds through different episodes of talk as a lesson unfolds over time. He recognized that if children are to have access to a scientific point of view, the teacher must at times establish what is already known by providing an authoritative account of factual information. Phil Scott showed how a timely combination of demonstration, clear teacher explanation, and the active involvement of students provides powerful contexts for classroom learning in science. For example, he showed students a tank of water standing on a table and asked for their ideas about what forces were at work. He asked them to consider whether the table exerts an upward force. Their uncertainty about this was resolved by asking them to take the place of the table and hold up the tank – or holding it up himself and showing what happened if the upward force was removed. He established that science teaching over the time span of a lesson, or series of lessons, proceeds through episodes that are more or less dialogic or authoritative in their nature – his insight being that authoritative episodes, where children are told things directly, are a crucial part of an ongoing dialogue. He recognized that teachers have the professional expertise to create lessons which draw on a range of strategies appropriate to the learning needs of the students, referring to this as "highly skilled guidance" in both discussion and science content.

The concept of "communicative approach" was first introduced by Eduardo Mortimer and Phil Scott to describe how a teacher works with children develop ideas in the classroom. The communicative approach is defined by characterizing the talk between teacher and pupils along each of two dimensions: interactive-noninteractive and dialogic-authoritative.

Interactive teaching involves talk between teacher and students, while noninteractive teaching involves only the teacher's voice. Dialogic teaching involves the teacher asking students for their points of view and explicitly taking account of them, asking for further details, or noting them for further consideration. In dialogic talk, there is always the attempt to acknowledge the views of others, and through dialogic talk the teacher attends to the students' points of view as well as to the scientific explanation.

During science sessions, a shift from dialogic to authoritative approach constitutes a "turning point" in the sequence of episodes. Phil Scott and Jaume Ametller showed how part of a teacher's professional expertise is to recognize key moments and carefully close down dialogic interactions. They could then provide a more authoritative, scientific point of view at times when it was clear that students were ready for an explanation of phenomena or an answer to the questions they had raised. Subsequent discussion in groups enabled students to talk about their new thinking and to examine the fresh perspective they had been given, in order to test its explanatory power, and to use appropriate vocabulary in ways that would support concept formation.

Science Concepts and Concept Formation

A child might know that sand is runny when dry and sticky when wet, without being able to say why. Some may not question this difference. But if asked, "Why do you think wet sand is sticky?" children will create everyday explanations drawing on their current vocabulary, experience, and creative imagination. A scientific explanation involves the concept of surface tension, an understanding of which requires learning about the molecular structure of water, hydrogen bonds, a consideration of particle size, and perhaps some thinking about gravity. Concepts are ideas created in our minds from various items of information and understanding. The label "surface tension" is in essence technical/scientific shorthand for a complicated chemical and physical effect. However complex the phenomenon, its outcomes – making sand sticky, making water droplets form – are easy to access and describe. The child may begin to use the label "surface tension" and only subsequently gradually accumulate the experience and information which deepen understanding. Concept formation is not an instantaneous effect but a gradual reconsidering and reshaping of ideas in the light of experience – and in the light of discussion with others.

This is a perennial dilemma for science educators – whether first to introduce accurate vocabulary so that experience is more readily describable or whether to first provide opportunities and experiences and only later provide the vocabulary necessary for explanation and concept formation. For example, a child might look at plant cells through a microscope and describe them as squares or rectangles. Another child might say bricks or boxes, and so the chance to talk about the three-dimensional nature of plant cells arises. The idea that living things are constructed from cells is fundamental to biology, and children have to start somewhere in learning this by observing cells. Whether we call them that at first seems to be a matter of opinion, based on the teacher's learning aim for their session. It is also important to note the metaphorical power of words – cells were named after the small rooms inhabited by monks. The chance to use the word "cell" aloud and in a science context, with other learners, provides invaluable practice and generates confidence.

The overlap between science terms and everyday uses of the same word can create confusion; for example, the commonly used words *energy* and *force* have particular technical meanings in science. Discussion of what is understood by particular vocabulary can help children to acquire a more scientific perspective as learning proceeds. Another example is the term *liquid*; this has a specific scientific definition, but young children may think that a liquid is sticky (washing up liquid). Similarly they may refer to any colorless liquid (e.g., molten candle wax) as water.

For individuals, science education proceeds both in startling leaps and in lengthy times of reflection and, seemingly, forgetting. But the ideas and words are held in mind and catch on the hooks offered by life – in and out of school. Learners may use new vocabulary in relevant contexts to build up an understanding of some important concepts or draw on their learning in what might seem unrelated contexts. So, if, for example, we consider teaching the concept "Waves have energy," it is possible to consider how a mix of activity, information, and discussion can provide an environment in which learners create this concept in their own minds. Allowing time for the mind to assimilate, try out, and integrate new ideas is crucial. It is also important to note that concepts like this can be taught to learners of any age. Bruner (1960) has written "You can teach any child any subject at any age or stage of development in an intellectually honest way." In primary settings, guided play, purposeful creativity, and chances to talk are the keys to tapping into children's interest in the world around them and helping them establish science concepts.

Analogies are widely used to explain and clarify science concepts, for example, considering current electricity to be analogous to a moving bicycle chain, a hosepipe filled with water, sweets passed around a circle of children, or a loop of rope running through their hands. No one analogy has complete explanatory power – no analogy can logically be exactly the same as the phenomenon it is held or relate to, but a range of analogies gives a concrete anchor for abstract ideas and therefore makes the abstraction more understandable.

With increasing understanding comes the opportunity to develop increasing complexity and to use other modes of communication, further specialized language, mathematics, and a range of ways to present data. Essential to science learning is an ability to communicate understanding to others so that knowledge is shared for further use. Without Newton's mathematical and verbal description of the forces that shape the universe, there would be no basis for Einstein's subsequent review and rethink of what we know about how the planets move. Without Einstein's ability to communicate his ideas to others – in 1905 he published three physics papers on the reality of atoms, the photoelectric effect, and on special relativity – his new explanations would not now be a basis for contemporary science thinking.

Summary

The careful accumulation of science knowledge has enabled us to understand more and more about how the world works. Because of this, we are no longer at the mercy of explanations of the natural world which are to do with imagination, superstition, or magic. The problems that can arise from applications of science, for example, in warfare, food production, human reproduction, and excessive global warming, are to do with human choices about how we use our knowledge, not the science itself. A sound science education is the right of every child. Through their learning of science, young people gain the opportunity to consider facts, issues, and ideas and learn how and why to discuss current causes of concern or interest with others. A discussion-focused approach to science education can support the child's development of concepts while teaching them how to take part in reasoned debate. Asking questions is natural. Science teaching can help young people to learn to collect evidence, to keep their curiosity alive, and to respect the world we all depend on.

Cross-References

- ▶ Alternative Conceptions/Frameworks/Misconceptions
- ▶ Cognitive Acceleration
- ▶ Conceptual Change in Learning
- ▶ Constructivism
- ▶ Dialogic Teaching and Learning
- ▶ Discourse in Science Learning
- ▶ Heterogeneity of Thinking and Speaking
- ▶ Socio-Cultural Perspectives on Learning Science

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Early Childhood Science Teacher Education

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Introduction

Early childhood education includes the study of children from birth to 8 years of age. Early childhood education has gained increased attention as governments around the world are putting more resources into supporting the quality of teaching and learning of very young children. The expectation is for children to learn more, including learning more discipline knowledge, such as science. Central to these increased outcomes has been the focus on quality provision of early childhood education through highly qualified early childhood teachers. So what do we know about the quality and experience of the graduates of our early childhood degree programs in science education?

A comprehensive search of all published literature into early childhood science teacher education (February 2012) revealed only 16 scholarly works. Thirteen papers were research studies and three were descriptive or theoretical discussions of specific early childhood science teacher education courses. This clearly suggests that early childhood science teacher education is an understudied area in urgent need of research attention.

The first published paper in the area of early childhood science teacher education was written by Margaret Bearlin in 1990 in Australia. Bearlin's paper remains the most insightful and critical analysis of early childhood science teacher education reviewed. Although a brief and multilayered study, it provides a seminal base for all the other papers that followed, where elements of the challenges identified by Bearlin so early on are investigated in a range of different contexts and theorized in different ways. On a macroscale, the problems facing early childhood science teacher education have not changed since 1990. After 24 years, we are no better informed and have made only incremental progress in furthering the findings set out by Bearlin in 1990.

So what did we learn from Bearlin's study, and what have most of the subsequent studies noted? We begin by examining the personal characteristics of early childhood preservice teachers, followed by discussing the institutional challenges and finally the societal and cultural values surrounding what it means to be an early childhood science teacher. Through this analytical framework, it emerges that teacher educators have generally either blamed the students for not having a science background or have designed courses to explicitly change the perceptions of the early childhood preservice teacher to one who can teach science successfully to young children. How the latter is achieved offers the focus for the rest of this entry.

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Personal Characteristics of the Early Childhood Preservice Teacher

In all the studies reviewed, a consistent message about the nature of the preservice learner was identified. Early childhood preservice teachers were found to be female, having studied some secondary school science, mostly human biology or biology, with very few having studied chemistry or physics. However, it must be noted that all the studies reviewed were from Australia, New Zealand, and North America (Florida, Georgia, Indiana, Midwest, New York, Ohio); therefore this profile can only be assumed for these European heritage communities. There is no easily accessible profile of early childhood preservice teachers in the Asia-Pacific continents, South American countries, Middle East, Soviet and Baltic communities, African continent, and central and northern Europe. This is specifically an under-researched area. We know most from the North American context.

As would be expected, those studies which assessed students' content knowledge of science showed that students had limited knowledge (Garbett 2003, 2007) and, with the exception of Garbett (2003), also lacked confidence in teaching in this area. Garbett (2003) found that the early childhood preservice teachers she surveyed in New Zealand believed they had sufficient content knowledge to teach young children science. However, her later results (Garbett 2007) showed that student teachers held many misconceptions, impeding their ability to ask appropriate questions or guide young children's investigations in ways that led to conceptual development in science. Here the preservice teachers were identified as not having the necessary background in science. Most studies reviewed, but particularly Garbett (2003, 2007) and Cullen (1999), strongly advocate for a focus in teacher education on building preservice teachers' science content knowledge, with Appleton (1995) arguing for two units of science education, where one unit should be devoted to learning science content knowledge (two units would typically be considered as half of one semester's study in a degree program). However, Appleton (1995) also argued for equal importance being placed upon building preservice teachers' confidence to teach science. Appleton's research which replicated that of Bearlin (1990) found that discipline knowledge needs to be introduced through experiences which support a positive self-image of students as teachers of science, where small group experiences rather than lectures appear to have the greatest impact on preservice teachers' self-image, but at the cost of reducing content coverage. These findings are consistent across all of the studies reviewed. Making sense of these collective findings becomes clearer by reviewing Bearlin's (1990) analytical framework for preservice teacher education.

Bearlin (1990) undertook a survey of practices in the 1980s of in-service and preservice programs, where she found three models for the teaching of science by teacher educators, which she used to inform the development of the Primary and Early Childhood Science and Technology Education Project (PECSTEP) which sought to specifically examine the relations between the historical disciplinary construction of science knowledge and the person. These models conceptualize and name the central problems that have plagued early childhood science teacher education programs since the publication of Bearlin's work in 1990:

Model 1: Subject-centered approaches focus on the body of knowledge that Western science has constructed and found to be a valued form of knowledge. In teacher education programs where this model dominates, educators primarily focus on ensuring that early childhood preservice teachers increase their conceptual knowledge of science concepts. This model tends to privilege the learning of concepts through process approaches devoid of theoretical underpinnings and does not pay attention to gender.

Model 2: Learner-centered approach tends to center on providing practical learning experiences to early childhood preservice teachers that are nonthreatening so as to increase their knowledge of science and gain experience of a range of science activities that are suitable for young children. Low self-confidence to teach science is linked with low science knowledge, and by increasing knowledge of science and science teaching, preservice teachers will increase their confidence and competence in teaching science. Gender issues are noted as not relevant because all children are unique. However, in some programs, specific course work is directed to analyzing the gendered nature of careers in science.

Model 3: Knowledge and person-centered approach is viewed as a gender-sensitive model where both science and gender are seen as constructed. Preservice student teachers are positioned in ways that help them value the knowledge they bring and to recognize the science concepts already understood and used in daily life. Through scientific experiences and inquiry that is based on their own interests (not the interests of children), preservice teachers reflect upon their own scientific learning and their learning about the nature of science as a human construction and not as a body of fixed knowledge. Consciousness about how science knowledge is constructed is the focus leading to the development of self-confidence and competence in science and later science teaching through using pedagogies such as interactive teaching.

Bearlin's (1990) work is noteworthy because the conceptualization and subsequent framing of the PECSTEP model recognized both discipline content knowledge and specifically the constructed nature of science, for what was then, and now, a predominantly female preservice teacher cohort in early childhood education. While the issue of gender has not changed, this highly significant variable in research has become invisible in subsequent years. With the exception of Akerson, Buzzelli, and Eastwood (2010) where issues of power are identified, and Siry and Lang (2010) who specifically created programs for cogeneration of scientific knowledge between the preservice teachers, the children, and the educators, issues of gender have not been further researched in early childhood science teacher education. Further to this is the cultural nature of science, which also remains invisible in early childhood science teacher education research. This too is an under-researched area within early childhood science teacher education.

Institutional Demands and Values (in the Field/in the University) that Shape What Is Possible for the Early Childhood Preservice Teacher

Most of the studies reviewed focused on the relations between the course content and experience of the early childhood student teachers in the university and their experiences on practicum. All science teacher education courses linked their course content explicitly with the practicum. A common problem identified across the studies was the lack of opportunities for preservice early childhood teachers to observe experienced teachers teaching science, and for many, there was also the challenge of not being allowed to teach science while on practicum. Many studies reported that there was never any guarantee that students would be able to practice what they were learning at university with children while on practicum. Consequently, many of the preservice science courses were designed with a range of creative solutions, such as:

1. Being given options for assessment work associated with the practicum just in case students' opportunities for teaching were limited or nonexistent (e.g., designing a science lesson plan and teaching it, designing a lesson plan that integrated science with another curriculum area and teaching it, designing a full unit because they were not able to teach science)
2. Watching videos and CDs of early childhood teachers teaching science
3. Computer simulations of science teaching

Many of these studies reported that literacy and numeracy were a higher priority than science, and consequently early childhood preservice teachers were either not given the opportunity to teach science or they had limited support when teaching science to young children from their supervising teachers in the field (see Lake et al. 2003). Two studies reported innovative ways of dealing with the institutional challenge of field placements being science-free zones. The PECSTEP developed by Bearlin (1990) and her colleagues sought to in-service practicing early childhood teachers in an interactive approach to teaching science. Preservice early childhood teachers were assigned to these same in-serviced teachers for their practicum placements. Siry and Lang (2010) developed a cogenerative dialogue between teachers, early childhood preservice teachers, and the children, where everyone had responsibility for reflecting upon both the pedagogy and the concepts that were the focus of the science lessons. Both approaches increased the quality and quantity of the field experience for the preservice teachers.

Comparing preservice teacher-generated philosophy statements against lesson plans and field practice was undertaken by Gilbert (2009) in order to support teachers with their inquiry-based approach to teaching science. However, changes to practice were still limited due to institutional constraints, such as pressures around assessment.

Garbett (2007) found that assessment practices which sought to encourage student teachers to create conversations with children around night and day in order to elicit scientific thinking were artificial and that conversations would be better if they occurred within everyday activities in which the children were already engaged.

A range of strategies to engage student teachers with scientific concepts have been noted across the studies, with educators trying to create authentic contexts that bring university course and practice in the field together in meaningful ways for students:

1. Models – student teachers reflect on expressed physical appearance of a scientific experience (e.g., volcano erupting) noting conceptual features (i.e., specific science concepts), followed by designing a model to explain what is happening scientifically (e.g., drawing the eruption as a model) which are included within students' lesson plans and used in the field (Kenyon et al. 2011).
2. Slowmation – students research the scientific concepts needed to create a slowmation with children (Fleer and Hoban 2012).
3. Comparing preservice teacher-generated philosophy statements against lesson plans and field practice (Gilbert 2009).

Institutional challenges were also met through the universities themselves. Jones et al. (2003) reported on a study of early childhood science and mathematics where they sought to specifically integrate these cognate areas in order to mirror the integration approach already prevalent in preschools. However, they noted that the traditional three-credit point model structure of teacher education programs made this difficult, as did organizing timetabling for integration and the challenge of transforming existing assessment approaches found within the university sector. While institutional practices directly shape what might be possible in science courses, societal beliefs about science and science teaching also determine how preservice teachers themselves feel about their role as science teachers. Taken together, these studies show that institutional constraints also work against what might be achieved in early childhood science teacher education programs.

Societal Expectations of Early Childhood Science Education

Societies support the learning of our youngest children through resourcing both material and human infrastructure and through the education of early childhood teachers and building and resourcing preschools. Curricula provide directions for early childhood teachers, and preservice early childhood teachers learn about these at university. Curricula are framed around specific theoretical traditions, and these have been noted in some of the studies reviewed. A number of studies from the North American continent draw attention to the interface between general early childhood curriculum which focuses on developmentally appropriate practice (or maturational theory of child development) and science curriculum which draws upon constructivism (Lake et al. 2003; Akerson 2004; Martin et al. 2005). A theoretical discontinuity is also noted in New Zealand where preservice courses link explicitly with their national curriculum – Te Whariki – which uses predominantly sociocultural theory for guiding early childhood teachers and constructivist theory for supporting science curriculum. Having two theoretical masters in the design and delivery of early childhood science teacher education courses is not only a challenge for the educators who teach in these courses but also the preservice students who must bring two different theoretical traditions together in the discipline area of science. This adds another layer of complexity to the design and delivery of early childhood science courses for female preservice teachers who already lack confidence in this area.

Other studies reviewed have drawn upon theory to explicitly develop student self-efficacy, such as Bautista (2011) who used Bandura's social learning theory or Siry and Lang (2010) who used critical theory to problematize power relations and to give agency to children and preservice students alike in the course of furthering scientific knowledge and confidence and competence to teach/learn science content. However, most science educators teaching early childhood preservice teachers science education have used pedagogical content knowledge and constructivism in the design and delivery of their courses. In these studies, no specific reference is made to the early childhood curriculum that the preservice teachers might also be following.

Knowledge traditions in many fields have continued to be developed over time. How science is viewed in society and how it is culturally constructed is important because it influences how preservice students perceive themselves as future educators of science. Akerson et al. (2010) study noted that early childhood teachers who plan and organize science learning do not necessarily reference this as science instruction/concept formation. They argue that because science experiences are not named as science to children or to teachers, early childhood preservice teachers do not necessarily perceive of themselves as science teachers. Their research found that preservice teachers' perceived beliefs about scientists were significantly different to how they perceived themselves. Preservice teachers believed scientists were highly valued and were powerful. In contrast they found that preservice teachers thought of themselves as valuing conformity (constraining action to avoid harming others), benevolence (concerned for others' welfare), and security (safety, harmony, stability of society). It was noted that in teacher education programs, educators should include in early childhood science courses a focus on the perceptions of preservice teachers themselves as teachers of science, rather than as only early childhood teachers. This was also supported by Bautista (2011) who used video observations and social learning theory to specifically improve the self-efficacy of student teachers. In Bearlin's third model of knowledge and person-centered approach to preservice education in science, how science is perceived and constructed in society, and how preserivce early childhood teachers perceive of themselves as teachers of science was foregrounded. Like Siry and Lang (2010), this model acknowledges the background of the student teachers and gives agency, rather than blames them, for the societal positioning of science as a highly valued form of cultural knowledge that represents power and authority to them (Akerson et al. 2010).

The highly valued place of science within society has traditionally been viewed as a body of knowledge to be learned and understood. Some of the programs reviewed reinforce this perspective, and in these programs, survey results suggest that student teachers' knowledge of science and capacity to teach science does not necessarily improve in the ways the educators hoped. However, in the studies reviewed which explicitly show preservice teachers that science is socially and culturally constructed by humans, and where they have the opportunity to create scientific knowledge around their own interests (e.g., Bearlin 1990; Appleton 1995), the survey results show that teacher competence and confidence to teach science significantly improves.

Summary

This entry into the Encyclopedia of Science Education is a limited set of studies which represent

Early Childhood Science Teacher Education, Table 1 Summary of research into early childhood science teacher education

References	Theoretical perspective	Focus of research	Methodology	Culture
Bearlin (1990) – see reference list	Constructivist	Gender-sensitive model of science teacher education	Survey and interview of course conveners; Pre- and post survey of 51 preservice teachers and 14 in-service practicing teachers	Australia
Appleton (1995) – see reference list	Constructivist	Student teachers' confidence to teach science: is more science knowledge necessary?	Pre- and post surveys of 139 students and 9 student interviews	Australia
Cullen (1999)	Cultural-historical perspective Overview article	Teacher knowledge of concepts	Theoretical discussion	International
Garbett (2003) – see reference list	Constructivist	Student teachers' confidence and competence through knowing concepts	57 surveys and written response; 73 survey of science knowledge (perceived and actual)	New Zealand
Jones et al. (2003)	Developmentally appropriate practice	Integrating science and mathematics in early childhood teacher preservice courses	Rationale for integration of science and mathematics in preservice courses	Florida, USA
Lake et al. (2003)	Constructivist	Transferring metacognitive processes from their integrated mathematics and science methods classes to their field classrooms	Analysis of children's journal entries being taught by 24 preservice teachers	Florida, USA
Akerson (2004)	Developmentally appropriate practice, Shulman's (1987) pedagogical content knowledge	Theoretical discussion on the role of the methods instructor in science teacher preparation	Description and principles for an early childhood science teacher education course	Indiana, USA
Martin et al. (2005)	Constructivist Developmental theory	Process-oriented approach to teaching science	Description of teaching approach using maturational model of child development	Georgia, USA
Fleer (2006)	Sociocultural	Examines early childhood preservice teachers' reasons for not teaching science	Theoretical discussion	Australia
Garbett (2007) – see reference list	Constructivist	Analysis of how assignments act as a pedagogy tool	Interpretive case study of 24 student assignments	New Zealand
Gilbert (2009)	Constructivist, process approach; focus on inquiry-based learning using the 5 Es model	Analysis of philosophy statements to facilitate K-3 teacher candidates' development of inquiry-based science practice	Analysis of 40 student teachers' philosophy statements, lesson plans, and reflections after teaching science	Ohio, USA
Akerson et al. (2010)	Cultural values	Determining the differences in the cultural values held by early childhood preservice teachers and scientists	17 preservice teachers were administered a *Schwartz Values Inventory*	USA

(*continued*)

Early Childhood Science Teacher Education, Table 1 (continued)

References	Theoretical perspective	Focus of research	Methodology	Culture
Siry and Lang (2010)	Cultural sociology, dialectical relations between agency and structure, critical theory (Henry Giroux)	Engaging children and preservice teachers in critical discourse about their experiences in science classrooms	Conversation analysis of video recording of 10 preservice teachers and 26 7-/8-year-old children and course instructor over a 10-week course	New York, USA
Bautista (2011)	Bandura's social learning and motivation theory	Self-efficacy as personal efficacy and outcome expectancy	44 pre- and post surveys (science beliefs to teach science)	Midwestern USA
Kenyon et al. (2011)	Shulman's pedagogical content knowledge (PCK)	Design approaches to support preservice teachers in scientific modeling	20 early childhood preservice teachers were involved in a three-phase design with iterative teaching and data gathering	USA (across three sites)
Fleer and Hoban (2012) – see reference list	Cultural-historical theory	Use of slowmation for engaging student teachers in learning science concepts	Two case studies	Australia and Singapore

the sum total of what has been researched in early childhood science teacher education to date. A summary of the studies is shown in Table 1 above which shows the range of studies, the details of the courses being taught, and the reliance on surveys for generating data on student experiences of their early childhood science teacher education course.

The work reviewed in Table 1 illustrates that simply giving more content knowledge of science to preservice early childhood teachers does not help them change their own perceptions of themselves as teachers of science. We know that educators of science education may be using a different theory to that which underpins the early childhood curriculum that they must work within their preschools. Many early childhood teachers draw upon one theory to support their work as early childhood teachers and another theory to support their work as teachers of science. We also know that institutional constraints in preschool and the early years of school reduce opportunities for observing and teaching early childhood science. The latter finding has not changed in 24 years. What seems to make the biggest difference to science content learning and confidence to teach science is when knowledge of science is gained through a change in how preservice teachers view the nature of science knowledge and see themselves as having a role in generating scientific knowledge to inform their own scientific thinking. We know some things. But we know very little about how countries other than Australia, New Zealand, and North America design and deliver early childhood science teacher education courses. This review shows that we have much to learn about how to effectively teach science education to early childhood preservice teachers in our current global community. But if the work of Bearlin has stood the test of time for over 24 years, then her research might be a good place to start.

Cross-References

- ▶ Curriculum in Teacher Education
- ▶ In-Service Teacher Education
- ▶ Pedagogy of Teacher Education
- ▶ Slowmation
- ▶ Socio-Cultural Perspectives on Learning Science

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Earth Science, Philosophy of

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Keywords

Abduction; Earth System; Historical science; Modelling; Multiple working hypotheses; Natural experiments

The philosophy of Earth science is concerned with how humans obtain and verify knowledge of the workings of the Earth system, including the atmosphere, hydrosphere, and geosphere (solid earth). Earth scientists' ways of knowing and habits of mind share important commonalities with other sciences but also have distinctive attributes that emerge from the complex, heterogeneous, unique, long-lived, and non-manipulatable nature of the Earth system (Chamberlin 1890; Frodeman 1995; Ault 1998; Cleland 2001; Manduca and Kastens 2012).

Most Earth processes do not lend themselves to experimental manipulation. Laboratory experiments have provided some important constraints on Earth processes: for example, methodical study of fluid flow in flumes has illuminated hydrodynamic principles essential to understanding rivers and sediment transport. But many first-order Earth phenomena, such as plate tectonics, global atmospheric circulation, biogeochemical cycles, and the structure of the Earth's interior can neither be brought into the laboratory nor manipulated experimentally in situ. As a result, Earth science relies heavily on methodical observation and construction of inference about plausible causal processes that could have led to the observed conditions – in other words on abductive rather than deductive or inductive reasoning.

The object of observation, the Earth system, is inherently complex and heterogeneous in both space and time. Across space, locales differ profoundly depending on whether they are continental versus oceanic; tropical versus polar versus midlatitude; on a tectonically active plate boundary or in a quiescent plate interior; or in mid-continent or mid-ocean versus a coastal setting. As a consequence, no single field area affords the opportunity to study the full range of Earth processes and conditions. Thus, of necessity, Earth scientists who seek answers to big questions are forced to think globally and draw evidence from across the planet (Manduca and Kastens 2012) and in some cases by comparison with other planets. Earth scientists exploit the Earth's heterogeneity by seeking out "natural experiments," circumstances in which an important causal factor or boundary condition varies naturally. For example, by comparing fast-spreading and slow-spreading divergent plate boundaries, geophysicists can isolate out the influence of this factor on volcanic and tectonic processes. Earth scientists favor explanations that cohere across multiple spatial scales (Ault 1998) and work back and forth between consideration of parts and wholes (the "hermeneutic circle" of Frodeman 1995). To reconstruct a complete sequence of a slow process, such as mountain building, Earth scientists "trade space for time" and look at multiple instances in different stages of development (Ault 1998).

Just as no single field locality exhibits the full range of Earth processes, neither does any single slice of Earth history, including the present. Thus, Earth science is an inherently historical science (Ault 1998; Frodeman 1995; Cleland 2002), like cosmology or archeology, but unlike physics or chemistry. To explore conditions when the Earth differed from the present, Earth scientists look to the past: paleoclimatologists examine the hothouse climates of the Cretaceous period and Eocene epoch, and petrologists contemplate the effects of the steeper thermal gradient of the Archean epoch. Observations of the Earth at any moment are typically a consequence of processes that are active at that time superimposed upon traces of past processes (Ault 1998). The historical perspective is most obvious in studies of the solid earth, where active erosion and weathering processes are superimposed upon sedimentary and tectonic processes of the past. But fluid earth processes are also historical, albeit on a shorter timescale; weather systems, for example, develop across time with each moment's configuration an outgrowth of its prior states.

Developing ways to disambiguate the traces of past and current processes and to reconstruct multiple generations of past processes was one of the first epistemological accomplishments of Earth science and remains an active area of research. Early insights include the principle of superposition (sedimentary layers are deposited in a time sequence, with the oldest on the bottom and the youngest on the top) and the principle of crosscutting relationships (the geological feature that cuts another is the younger of the two). Areas of active research involve detecting and exploiting various physical, chemical, and biological traces of past processes in ways that provide constraints on the timing, rate, and/or sequence of past events. Earth scientists care about timing and sequence because sequence constrains causality: if A occurred before B, then A can have caused or influenced B, but B cannot have caused or influenced A. Earth scientists care about rates because rate constrains power: to transport a given volume of sediment or rock or water or air in an hour requires a more powerful causal process than to accomplish the same effort in a day or year or decade or millennium.

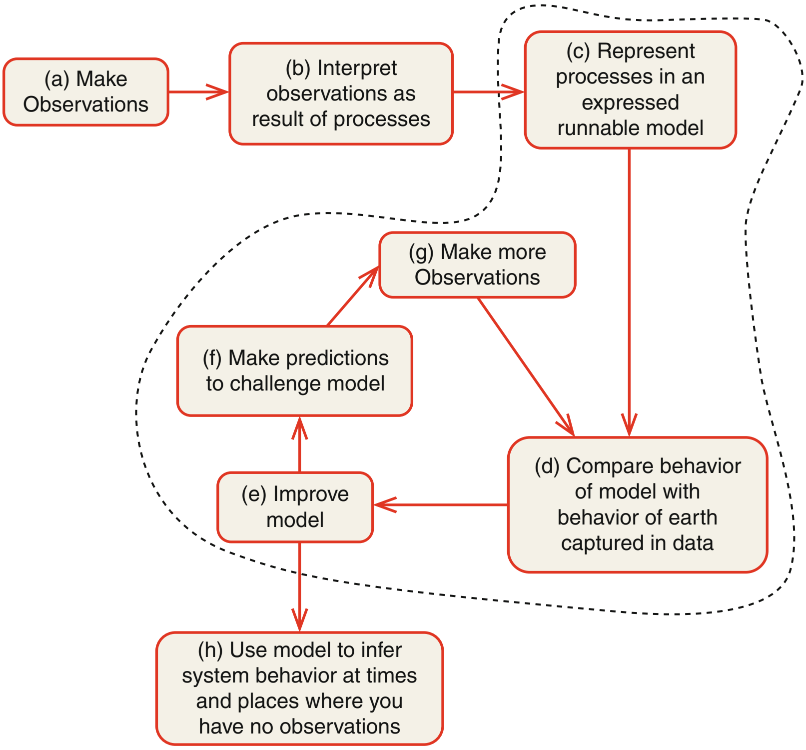
The Earth system exhibits other forms of complexity, in addition to spatial and temporal heterogeneity. Rather than seeking the simplest or most parsimonious explanation, Earth scientists are comfortable with explanatory schemata that invoke emergent phenomena and multiple intertwining feedback loops (Manduca and Kastens 2012). For more than a hundred years, since the writings of Chamberlin (1890), Earth scientists have favored an approach of multiple working hypotheses, rather than a single null hypothesis. Chamberlin used the example of the Great Lakes, which had been hypothesized to be carved, by rivers, or scooped out by glaciations, or deepened by flexure under the weight of ice. In fact all three hypotheses were part of the answer, and Chamberlin used this example to recommend the use of multiple working hypotheses as a habit of mind suited to understanding complex phenomena. To weigh such multiple possibilities, Earth scientists seek distinctive traces of each hypothesized process or event in empirical data. Cleland (2001) calls such decision-supporting traces "the smoking gun," explicitly yoking the reasoning of Earth scientists and detectives.

Progress in modern Earth science is highly dependent on distributed cognition, thinking that is distributed across multiple minds and across human brains working in collaboration with cognitive tools. Because of Earth's complexity, heterogeneity, and fragmentary record, clues to any important Earth science puzzle are likely to be scattered across space, across time, and across disciplines. Thus, important insights in Earth science commonly rely on collaborative merging of lines of evidence developed by different individuals or groups (Manduca and Kastens 2012), any one of which would be unpersuasive but when taken together constitute a sufficient preponderance of evidence to be accepted as a provisional consensus interpretation (Ault 1998). For example, the acceptance of the impact origin for the mass extinction at the Cretaceous/Tertiary boundary relied on evidence from Italy, New Zealand, Denmark, New Mexico, and the Caribbean and from paleontology, stratigraphy, nuclear chemistry, geophysics, isotope geochemistry, marine geology, astrophysics, and paleoecology.

Until a decade or so ago, most Earth scientists thought about the past, either the distant past (e.g., stratigraphers) or the immediate past (e.g., seismologists). Meteorologists thought about the future, but only 3–5 days into the future. In the twenty-first century, however, society is asking the Earth science community tough questions about the future: when will there be another destructive earthquake or hurricane here? How fast will sea level rise? How warm will the climate become? Thinking about the future rather than the past requires a different epistemology (Cleland 2001). In particular, thinking rigorously about the future requires a model. In science education, "model" typically refers to a conceptual model, i.e., an idea or interpretation, and "modeling" typically refers to the process of developing and articulating such an idea. But the computer models used in modern Earth science research are more than simply ideas or representations of ideas. They are cognitive tools, which unload cognitive burden from human scientists' brains and display observable behavior that becomes part of the evidentiary base of science.

Figure 1 sketches the process by which the Earth science community creates new knowledge about the Earth system using models such as global climate models. Scientists make observations (a) of the Earth system and interpret those observations as being the result of processes (b). They represent those processes in a physical or computational device (c), then activate the device (i.e., "run" the model), and compare the behavior of the model with the behavior of the Earth as captured in data (d). Where the model behavior and the behavior of the Earth do not correspond, they improve the model (e). They then use the model to make predictions of how the Earth should behave under a set of non-yet-observed conditions (f). They collect more data (g) and once again compare the behavior of the model with the behavior of the Earth as captured in the new data (d, again). For a complex system, there can be many trips around this circle (d-e-f-g-d), involving many research groups and many data types. Only after a model has been refined by repeated trips around the improvement circle, yielding fewer and smaller areas of non-correspondence between model behavior and Earth behavior, does the model earn the credibility to be used to make inferences about times and places for which no observations are available (h) – such as the future.

In summary, Earth scientists' ways of knowing emerge from the nature of the object of study (Ault 1998; Manduca and Kastens 2012). Because the Earth is not amenable to experimental manipulation, Earth scientists' ways of knowing are characterized by use of spatial and temporal lines of reasoning, lines of reasoning that leverage the Earth's heterogeneity by taking advantage of "natural experiments" in which candidate causal factors have varied over space or changed over time. Because the Earth is a complex system, with multiple interacting subsystems, Earth scientists' hypotheses tend toward complex systemic explanations rather than privileging the simplest



Earth Science, Philosophy of, Fig. 1 Schematic view of how Earth scientists create new insights about the behavior of the Earth system using expressed runnable models such as climate models. The *dashed line* encircles parts of the process that are not often seen by the public or by students (From Kastens et al. 2013)

explanation. Because the record of Earth's past is fragmentary, leaving only scattered clues, Earth scientists tend to construct interpretations collaboratively, drawing from multiple field areas and subdisciplines. In order to think rigorously about times and places for which no observational data are available – including the future – Earth scientists are increasingly relying on distributed cognition not only across multiple research groups but across computational tools as well as human brains.

Cross-References

- ▶ Biology, Philosophy of
- ▶ Chemistry, Philosophy of
- ▶ Epistemic Goals
- ▶ Mechanisms
- ▶ Science Studies
- ▶ Scientific Visualizations
- ▶ Social Epistemology of Science
- ▶ Sociology of Science

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Ecojustice Pedagogy

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Ecojustice in Science Education

Ecojustice philosophy merges social and environmental justice theories by emphasizing physical, spiritual, and emotional connections between an environment and the residing social group. It is concerned with environmental issues in a variety of ways including equity in relation to non-Western cultures, abuse of indigenous groups through land exploitation, economic prosperity in conjunction with land use, and modification to the environment in other ways that benefit particular lifestyles. Researchers such as Bowers (2002), Mueller and Tippins (2011), and Sachs (1995) present ecojustice philosophy as a way to make the global more local and encourage decision-making skills across intergenerational contexts. In terms of science education, these researchers maintain that ecojustice philosophy can help in creating democratic environments with learning taking place as a mediated process to encourage participation and action by multiple parties. They further emphasize that it can open the door to learning in different contexts while maintaining a focus on the relationship between society and ecological awareness, preservation, and sustainability.

What Are the Basic Tenets of Ecojustice Philosophy?

Ecojustice philosophy attempts to balance the tensions between cultural systems and environmental systems by analyzing what resources should be conserved and how the use of these resources can be less taxing on ecological and cultural systems. Three distinct components of ecojustice philosophy which make it unique are a focus on cultural assumptions and challenging these, a deeply rooted belief in local action, and an opportunity for the voice of the other to be recognized.

Challenging Cultural Assumptions

A key aspect of ecojustice philosophy is an awareness of cultural assumptions with the recognition of how they influence both thought and action in relation to "others." Foundational beliefs derived from our lived experiences, cultural knowledge, and traditions shape our actions, behaviors, and values. Ecojustice philosophy encourages the uncovering of our cultural ideas and analysis of those assumptions. From this perspective, it is only when value is acknowledged as existing outside of our known that we can begin to enact the actions of promoting justice. In terms of ecojustice, enacting a different mindset comes when what is seen and felt challenges what was thought to have been the ideal. The idea of challenging assumptions is enhanced by the emphasis on local, promoting a view from within which can possibly allow change to occur more readily.

Local Action and Intergenerational Knowledge

Ecojustice philosophy is informed by a belief in the importance of local action and knowledge which can foster responsibility, develop ownership, and encourage involvement and awareness for others. When action represents the "safekeeping" of what is known, the door is then opened for encouraging how individuals might contribute to the protection of the other. At the local level, action allows for familiarity and investment. Sachs (1995) shares several examples of large-scale environmental projects which were implemented and enforced because of a local belief that areas needed protection. When action is implemented by individuals unfamiliar with the community, the cultural use and value of that area are often overlooked. From an ecojustice perspective, local needs should be considered before large-scale decisions are implemented, with an emphasis on involving local citizens to enact policy for their own community. Ecojustice philosophy promotes local action, highlighting contextually specific knowledge that can only be ascertained when there is direct contact with a people and place, with experiences that span generations. A focus on making the local paramount allows for *all* to have a voice; the place, beliefs, customs, and nonhuman inhabitants are heard together with the people.

Empowering the Voices of the Disenfranchised (People or Places)

Inherent within ecojustice philosophy are the personal interactions that promote a voice which is inclusive of living and nonliving, the visible and the invisible. In this sense, ecojustice calls for the equitable sharing of resources between all individuals on the planet, not just humans. This means that when decisions for "progress," "development," and "growth" are considered within a community, society will have to look beyond just the needs of *Homo sapiens* and consider the requirements of other species and ecosystems that will be impacted by such actions. Ecojustice philosophy extends social justice theories to argue that the inequitable distribution of power that ranks humans over nonhuman species or even some humans over others (related to class, race, gender, etc.) is unjust but is passed on through cultural norms such as language. Thus, ecojustice philosophy aims to create an intersection for teaching and environmental equity with science content, process, and pedagogy.

Other Dimensions of Ecojustice Philosophy

Ecojustice philosophy is grounded in uncertainty theory which acknowledges the degradation of Earth's resources as a result of human actions such as consumer-focused lifestyles, overutilization of technology, and the commodification of nature. Bowers (2002) claims that most citizens of Western culture fail to recognize that their consumer-oriented lifestyles, which are explicitly and implicitly encouraged by their society, are directly related to the decline of environmental and/or ecosystem health. Furthermore, according to Bowers, the formal education system is often a powerful force in maintaining the status quo of consumerism and globalization. Ironically, it can also be one of the most promising forces for developing in students a deeper understanding of how these cultural norms are negatively impacting the environment.

What Is the Role of the "Commons" in Ecojustice Philosophy?

In order to embrace a holistic view of sustaining other cultures and the Earth's natural systems, ecojustice philosophy emphasizes the importance of communities working to protect and revitalize their cultural and environmental "commons." The concept of the "commons" is multifaceted in nature. According to Bowers (2002), the commons, historically, were the environmental aspects of the community required for subsistence: pastures, forests, lakes, streams, etc. In other words, the commons were the aspects of the environment that citizens depended upon to provide for their families. More recently our understanding of the commons has expanded to include more intangible items: air, language, narratives, craft knowledge, and technology, to name a few. These are aspects of the community and culture that are common to the majority of individuals of an area even though they are not "owned" by any one person and cannot be bought. What is important from an ecojustice perspective is the way in which human cultural practices and natural systems interact. An understanding of the ways in which the cultural and environmental commons intersect requires teachers and students to develop thoughtful awareness of cultures and traditions that both sustain and oppress social and ecological well-being. In today's world, this is essential as more and more knowledge generated within the commons becomes enclosed and vulnerable to extinction.

Ecojustice Philosophy Framed Within Science Education

Martusewicz et al. (2011) describe the important role that science teachers play in helping their students become "aware of the rich practices and knowledges-the assets-in local communities, involving their students in work that is focused on protecting independent relationships that are part of the intricate living systems" (p. 20). In this way, an ecojustice philosophy argues that educating individuals is a critical aspect of ensuring resource availability for future generations, the revitalization of the commons, and development of a more just society. Of course teachers need to be educated themselves about matters of ecojustice and sustainability in order to teach about them in ways that are embedded in the local community.

In science education, several important pedagogical trends have emerged in recent years that reflect the basic tenets of ecojustice philosophy: place-based education, citizen science, and socioscientific issues and reasoning. Place-based education focuses on grounding learning in local phenomena and students' lived experiences. For teachers, and by extension their students, this means forming meaningful connections to other people and the community or the environment in which they live. These personal connections actively work against the forces of globalization which act to enclose the cultural and environmental commons. Citizen science is another ecojustice pedagogy which is uniquely situated to bridge the growing chasm between professional science and science education. Traditional top-down approaches to citizen science involved local individuals in collecting data for the projects of scientists with little opportunity to participate in the formulation of questions or analysis of data with relevance to local issues. The more recent movement toward the "democratization of citizen science" (Mueller et al. 2011) has provided exciting opportunities for students to view science as something to which all individuals can contribute, for example, through environmental monitoring and habitat restoration projects. This reconceptualized citizen science movement (referred to by some as the public participation in science) repositions teachers and students as producers of scientific knowledge and legitimate members of the extended scientific community. Socioscientific issues and reasoning about these have also been characterized as a pedagogical approach consistent with ecojustice philosophy. Socioscientific issues are social dilemmas with conceptual or technological links to science that require students to engage in a degree of moral reasoning or evaluation of ethical concerns in the process of arriving at decisions regarding possible solutions. Increasingly, as science educators work toward a philosophy of ecojustice which recognizes uncertainty thinking and values cultural pluralism, intergenerational knowledge, and narratives, other pedagogies will be recognized as alternatives to a decontextualized science education.

New Pathways and Directions: The Importance of Mindfulness in Ecojustice Philosophy

How can science educators help students process experiences and question their assumptions in ways that increase awareness and knowledge of others? Research shows that students are more apt to apply knowledge in this way when principles of mindfulness are part of the instructional framework (Frauman 2010). To encourage mindful behavior, hypothetical "what ifs" become especially useful. Rather than promoting a set of rules that will be adopted as second nature, mindfulness research points to the need for increasing the level of thought behind particular actions. In this regard, science educators should propose situations that require student action and allow time and opportunity for dialogue for determining what should happen, rather than presenting things as resolved with little thought as to how they came to be. Mindfulness includes greater exposure to specific settings and consists of higher-order considerations for relationships. Mindful thinking enhances awareness for multiple perspectives, highlights relationships to immediate surroundings for more personally relevant interactions, and includes group responsibility that in turn encourages ownership and greater concern for the local.

Mindfulness is a crucial learning outcome which has been linked to co-generative dialogue. Co-generative dialogue involves multiple stakeholders in conversation that expands the base of knowledge and recognizes the diversity in voices which are intimately associated with creation and recognition of knowledge. Co-generative dialogue encourages mindful behavior and aligns with ecojustice philosophy by increasing awareness of the other and enabling the voice of the disenfranchised to be recognized as equal and valuable, through group dialogue and deliberation. Mindful behavior is an expected outcome of group interaction when there is a moderating voice, but what happens when participants are encouraged to undertake self-analysis and dialogue occurs within rather than between? Within ecojustice philosophy, both self and group encounters play a role in how understanding develops. Yet, mindfulness is more likely to be based on individual perceptions rather than knowledge and beliefs established as truths by the group. Within science education, specifically within the frame of ecojustice, mindfulness can be encouraged by promoting engagement within the familiar and providing the opportunity to question what is often common. Meaningful encounters within the local that include open and continued dialogue, in and about these spaces, enable knowledge of self, the unheard, and the experiences of the communal whole to be further developed.

Implications of Ecojustice Philosophy for Twenty-First-Century Learners: Some Challenges

In a time when youth in industrialized countries are very commonly more disconnected from the natural world than any previous generation in human history, ecojustice philosophy has great potential for making a difference in the way educators frame twenty-first-century science education around principles that may challenge traditional conceptions of scientific literacy. How does one both encourage community involvement in ways that increase the dialogue between partnering groups and multiple generations and decrease vulnerability to outside (and often opposing) forces, forces which deemphasize the value found in locally constructed knowledge?

There are challenges educators often face when attempting to implement reforms informed by ecojustice philosophy.

Challenges

The personal involvement at the heart of ecojustice philosophy makes it very appealing, even when the drawbacks of language, context, and "local" are considered. One of the greatest obstacles involved with ecojustice philosophy is the lack of a shared language, an open dialogue in which all players have equal value and voice to enact change. An open forum for dialogue would provide the common ground necessary for shared knowledge essential to cultivating students equipped to make informed decisions and participate more fully in advocating for Earth's natural systems and other affected parties. Without consistency in the conversation and without the existence of a continued conversation, ecojustice philosophy may never be utilized to its fullest. Learning networks must be built between the school and community as a starting place for conversations which value locally constructed knowledge and experiences.

Ecojustice philosophy is both situational and contextual which poses an additional challenge. It is situational in that opportunities exist in location and relation to something and contextual in that experiences of one event happen within specific parameters that cannot often be replicated. Having an experience and hence beginning understanding of one event may enable meaning to evolve, yet the specific actions are not always replicable elsewhere. These situational and contextual aspects limit transferability and make enactment of ecojustice philosophy challenging. Decontextualized international, national, and state standards, in particular, are troublesome issues for ecojustice and place-based reforms. While ecojustice alternatives are starting to stimulate science education reforms in the directions argued above as appropriate, they may be limited by the significance of how local matters are viewed by policymakers. Teachers and students, in many cases, are often displaced by the priorities of high-stakes tests. This is a predicament which deemphasizes or ignores the responsibility of schools to cultivate students who can participate fully in local decision-making.

Another challenge to using ecojustice philosophy involves its focus on local issues and the emphasis on growing community knowledge so as to avoid being vulnerable to outside influence, such as harmful new industry or economic imperatives that undermine the greater good of the "whole" community. With such interference, knowledge held within a community does not necessarily get passed to future generations. This intergenerational aspect of ecojustice philosophy carries with it the question of how wisdom is imparted to other generations. What relationship must develop between the community and school to encourage solidarity, scientific literacy, and action when outside forces oppose what is best for the local? A continuing challenge in current science education rhetoric is the isolation of school from the local community. While this is not insurmountable, it can prove difficult to connect the voice of the student, local ecosystem, elder, business person, and concerned citizen. Ultimately, for schools in the twenty-first century to capture the meaningful purposes of educational reforms that reflect ecojustice philosophy, teachers and students must be repositioned as producers of science and participants in ecological decisions.

Cross-References

- ▶ Citizen Science
- ▶ Cultural Influences on Science Education
- ▶ Discourse in Science Learning
- ▶ Immersive Environments
- ▶ Knowledge-Building Communities
- ▶ Meaningful Learning
- ▶ Public Engagement in Science
- ▶ Science for Citizenship
- ▶ Social Epistemology of Science
- ▶ Socioscientific Issues
- ▶ Sustainability and Science Education

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E-Learning

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Keywords

Online learning

E-Learning

E-learning (electronic-learning) refers broadly to the use of information and communication technologies for the electronic delivery of instructional content and the support of educational processes. Computer-supported learning can vary from being completely "self-paced," with no human instructor, to being highly coordinated, with the instructor interacting with students at a distance. Thus, it is a broad concept that encompasses such phrases as *online learning*, *Web-based learning*, *computer-based instruction*, *Web-based training*, and *virtual education*. E-learning systems have been developed for many different purposes and audiences, for both formal and informal learning contexts. With the rapid growth of the Web over the past decade, the popularity of the term *e-learning* has faded slightly, in favor of the more widely used term, *online learning*. However, both terms still appear regularly in the media, and the phrases e-learning and online learning are often employed interchangeably.

The earliest e-learning systems, developed in the 1960s, explored how computer programs running on mainframe computers could be used to teach children mathematics and reading. This type of learning, which was referred to as *computer-assisted instruction (CAI)* or *computer-based learning (CBL)*, took the form of individualized lessons in which the computer systematically guided the learner though an instructional sequence concerned with a particular topic. In addition to presenting instructional content, these programs often contained a diagnostic or evaluative component that allowed the software to assess student comprehension, provide remedial exercises where necessary, and adjust the sequencing of the material to accommodate the learner's needs. This trajectory of work remains active, within a discipline known as "intelligent tutoring systems."

The notion of e-learning has broadened significantly and is now associated with rich, Web-based multimedia content (e.g., text, images, audio, video, and animation) and a greater level of student control and autonomy. Some e-learning still takes the form of individualized, one-way instruction, such as through video-taped lectures or screencasts, which are widely available on the Web (e.g., Khan Academy). However, other e-learning environments engage learners in online interactions with a human instructor or peers.

Tools like wikis, blogs, asynchronous online forums, real-time chat, instant messaging environments, and many-to-many videoconferences (Webinars) provide supports for group discussions, student collaboration, and the sharing of resources. Some popular e-learning environments, like Moodle and Blackboard, incorporate many of these tools so that instructors can use them in combination. By designing shared online activities and assignments, e-learning instructors can foster a sense of online community in which students work collaboratively to build on peers' ideas and deepen their understanding of the course content.

Current e-learning environments are usually media-rich and Web-based, with some level of support for social interactions and a significant degree of learner control. Screencasts and course management systems like Moodle and Blackboard are widely used. Educational "apps" on handheld devices and desktop computers can also be considered as forms of e-learning. Several modern forms of e-learning are still experimental in nature. For example, the educational potential of immersive virtual environments, like Second Life, is still being studied. Massive open online courses (MOOCS), in which tens of thousands of people may be simultaneously enrolled in a course, represent another relatively new type of e-learning, one that is distinguished by an unusually large number of learners and open access via the Web.

Cross-References

- ▶ Digital Resources for Science Education
- ▶ Online Inquiry Environments
- ▶ Technology for Informal and Out-of-School Learning of Science

Embedded Assessment

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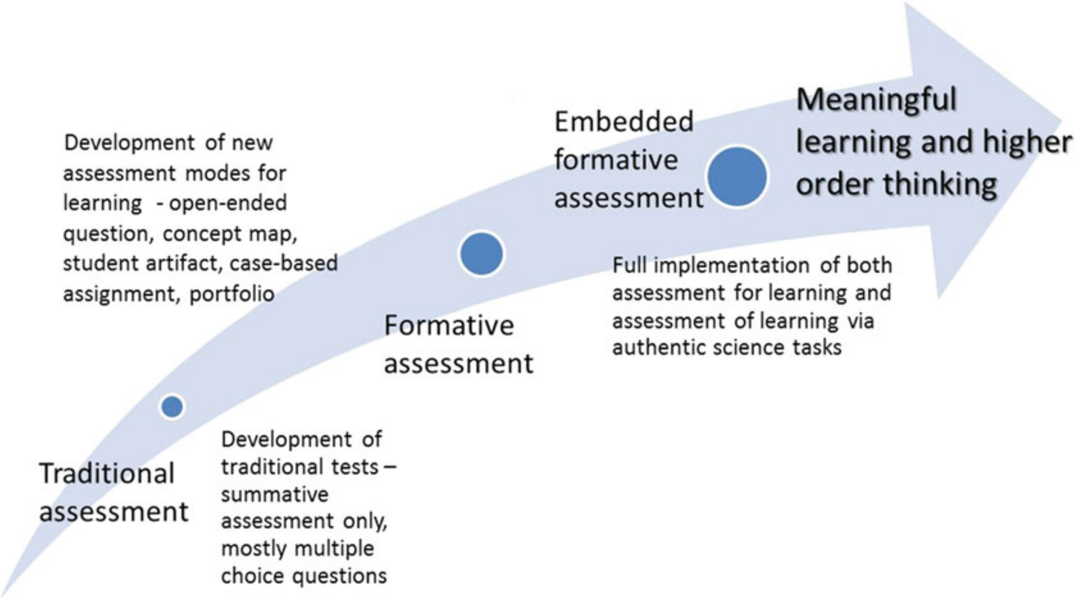
Keywords

Assessment; Assessment methods; Authentic assessment; Authentic science tasks; Curriculum-embedded formative assessment; Formative assessment; Formative embedded assessment

Over the past three decades, western educators and researchers alike have sought for novel ways of assessing students' authentic mastery learning, as well as their understanding of curricular concepts and content continuously throughout a course. Embedded assessments (EAs) aim to assess a broad range of students' abilities and comprehension continuously throughout the learning process (Pellegerino 2002–2003). This ongoing assessment enables teachers to (1) assess students' content knowledge and skills by gathering information on students' abilities to understand and reason, (2) make sense of the information and work towards closing the gap between where students are and where they should be, (3) guide the shaping of teaching plans, (4) make adjustments in response to students' difficulties, and (5) find different ways to attain conceptual understanding and science skills (Furtak et al. 2008).

Valuable EAs constitute authentic, nonroutine, and multifaceted science tasks with no obvious solutions. Often, when teachers implement formal EAs effectively via authentic science tasks in school settings, students achieve higher scores on summative assessments in comparison to students who experienced traditional tests only. More importantly, valuable EAs engage students in active participation and enable them to creatively demonstrate their knowledge of a concept, a process, or a scientific skill while they respond to an authentic assignment in the science classroom (Dori 2003).

Embedded assessment is aimed to serve as formative assessment; thus, it is used as assessment for learning rather than assessment of learning. Ayala et al. (2008) describe five steps for designing and implementing formative and embedded assessments that demonstrate an understanding of topic-specific content, which are linked to the overall goal of the curriculum. EA development may be guided by the "conceptual framework for science achievement" (Ayala et al. 2008), which creates a rubric for science achievement and reasoning with four overlapping types of knowledge: declarative, procedural, schematic, and strategic. It is crucial to specifically place EAs at meaningful points in the learning process, to ask students to reflect on their learning, and to provide them with instant feedback necessary to bridge the gap between students' current knowledge and what they are expected to know (Ayala et al. 2008; Dori 2003; Shavelson et al. 2008). Only then can teachers modify their teaching style accordingly (Dori 2003; Shavelson et al. 2008). These researchers assert that when formative and embedded assessments are combined and implemented, the knowledge acquired by students is elevated and their understanding is improved, thus leading to improved learning outcomes, generally measured by end-of-year standardized, multiple-choice exams. The improvements are seen in students' coherence and comprehension of knowledge while addressing and assessing the broad range of students' learning methods and abilities (Pellegerino 2002–2003). In curricular milestones or junctions, it is important that teachers analyze their task or question choice, quality control of data assessment, and the ways in which science assignments and tasks are assembled and communicated with the students. These kinds of assessments, which are part of the teaching and learning process, provide



Embedded Assessment, Fig. 1 From traditional assessment to embedded formative assessment in science classrooms

every student with an individually constructed opportunity for learning (Shavelson et al. 2008). Although the science assignments may not always have a final grade, they should be well organized, made overtly clear to students, and presented as learning opportunities. These scientific tasks need to be integrated with the students' own conceptual understanding of the topic while they take part in the process of moving towards the ultimate goal of the specific course, on one hand, and gaining scientific and thinking skills, on the other hand (Dori 2003; Pellegerino 2002–2003). Successful implementation of embedded assessment resonates deeply with successful organizational collaboration, that is, teacher-student and teacher-curriculum developer. The two work together best when all parties demonstrate similar and/or compatible philosophies and show awareness of their respective resources, experiences, knowledge, and skills while working together towards a mutual goal. Thus, teachers must take part in an ongoing training and be provided with professional development tools that guide them towards a new conceptualization of the value of assessment, especially EA, compared to summative assessment alone. Through hands-on testing of EAs in a real-world school setting, the main variable in predicting their success was the teachers' pedagogical content knowledge and assessment knowledge as well as their willingness to implement educational reforms (Avargil et al. 2014; Ayala et al. 2008).

Before implementing EAs in actual science classroom settings, teachers should receive an ongoing professional development and mentoring on how to implement EAs, combined with reflection upon their lessons and tasks they developed for their own students (Avargil et al. 2014). This will provide them with the opportunity to reevaluate their approach while teaching a new curricula's material and an opportunity for their students to concretize the scientific concepts, processes, and thinking skills implemented until this particular EA's junctions (Ayala et al. 2008; Dori 2003). As shown in Fig. 1, embedded formative assessment may foster students' meaningful learning and is aimed at developing students' higher order thinking skills, especially in science.

Cross-References

- ▶ Assessment: An Overview
- ▶ Authentic Assessment
- ▶ Formative Assessment
- ▶ Teachers' Understanding of Assessment

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Emotion and the Teaching and Learning of Science

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Keywords

Emotion; Emotional climate; Emotional engagement; Facticity; Positive emotional energy

With the exception of extensive research on test anxiety, research on emotions experienced by teachers and students in classrooms is still in its infancy. In particular, little research has explored the emotional arousal of classroom participants in the teaching and learning of specific subject matter such as science (Rosiek and Beghetto 2009). However, overall, it is now clear that emotions have a profound effect on students' and teachers' interest, engagement, performance, and achievement. In short, emotions appear to be central to understanding teaching and learning (Pekrun and Schutz 2007). Moreover, the centrality of emotions to daily life is evident in the realization that every dimension of society is held together or ripped apart by emotional arousal (Turner 2007).

Defining *emotion* has been an elusive challenge because it can be studied from a variety of theoretical perspectives. Emotions can be viewed as the complex of causal effects among four interrelated elements, namely, situational cues (e.g., behaviors relevant to achieving a specific task or goal), physiological changes (e.g., heart rate, blood pressure), emotion labels (e.g., happiness, anger, fear, sadness), and expressive gesture (e.g., facial expressions, hand gestures) (Turner 2007).

Michalinos Zembylas' extensive reporting of his 3-year ethnographic study of science teaching and learning in an elementary teacher's classroom not only reaffirmed the pivotal role of emotions in teaching and learning (e.g., Zembylas 2004) but also showed how emotional practices could be constructed by the teacher and her students. Yet, the social-constructivist perspective underpinning the study is limited because the arousal of emotion is not simply a labeling or socially constructed process but also involves neural transmissions and physiological functions that can be triggered automatically without conscious effort. This suggests that an integrated theory that embraces rather than ignores the biology of emotions, such as Turner's sociology of human emotions, offers a promising way forward to researching emotions in educational contexts (Turner 2007).

Most scholars agree that the four primary emotions are the following: satisfaction-happiness, aversion-fear, assertion-anger, and disappointment-sadness, which Turner (2007) presumes are hardwired in human neuroanatomy. Some scholars add surprise and disgust to this list. These primary emotions can be experienced at different levels of intensity and in various combinations that denote the more complex emotions such as shame and guilt. Interest, boredom, and curiosity are sometimes included on lists of emotions, but other times excluded because they are considered cognitive states (Turner 2007).

A series of studies conducted by Ritchie and his colleagues (see: http://profiles.murdoch.edu.au/myprofile/stephen-ritchie/) in a variety of secondary science and teacher education classroom contexts embraced Turner's theoretical framework that also incorporates related sociological constructs such as *positive emotional energy* generated from successful interactions. They accept that positive emotional energy is a strong steady emotion that affords participants the capacity to act with initiative in the micro-details of interaction that manifest in confident and rhythmically synchronized body movements, eye contact, facial expressions, and vocalizations (Collins 2004). For example, a science class that responds to a group role-play by laughter followed by spontaneous applause demonstrates positive emotional energy. The beginning teacher at the center of one study found *dialogic interactions* were positive and satisfying experiences for her (i.e., she experienced the discrete positive primary emotion of happiness), and she was motivated to reproduce these interactions successfully in different contexts. Both teacher and her students used humor to create a structure for dialogic interactions. In terms of Turner's theory, positive emotional energy was observed during successful interactions between the teacher and groups of her students when the students achieved the teacher's expectations, and the teacher experienced negatively valenced emotions (e.g., disappointment) when the students did not achieve her expectations. In a related study of beginning physics teachers as they implemented inquiry projects, similar results were reported. Teachers experienced positive emotions in response to their students' success during the research projects. When student actions/outcomes did not meet their teachers' expectations, frustration, anger, and disappointment were experienced by the teachers. Over the course of the projects, the teachers' practices changed along with their emotional states and their students' achievements, suggesting that emotions are also important in teacher learning.

This program of research departs from most other studies of emotions in science classes because it explores new and multiple research methods to identify discrete emotions aroused by students and teachers during their classroom interactions as well as to measure the experienced classroom emotional climate. *Emotional climate* of a classroom is the collective state of emotional communion between classroom participants in which the salience of self for individuals decreases as the collective identity of the class is enhanced. Positive emotional climate is related to expressions of happiness and joy and a sense of group belonging and social integration. Similarly, negative emotional climate is associated with expressions of sadness, fear, and/or anger within a group. External raters and classroom participants as internal raters of emotional climate have been employed to explore classroom emotional climate. Students have used audience-response technology (i.e., "clickers," where students record their perception of the emotional climate on a five-point scale by pressing the appropriate key which sends the signal via Bluetooth to a computer) to rate the emotional climate at short intervals such as 3 or 5 min across whole lessons. The results show that the classroom climate varies moment to moment in a series of events represented graphically as peaks and troughs that can be explored microanalytically through conversation analysis of video recordings and analyses of prosody, facial expressions, and gestures.

Audience-response technology also has been used in science teacher education classes where students identify their perceptions of emotional climate and, more recently, their discrete emotions experienced at regular 5-min intervals. The discrete emotions currently being investigated include the following: enthusiasm, happiness, attentiveness, neutral, disappointment, annoyance, and boredom.

The *emotional engagement* of high school science students during activities that focus on socioscientific issues (SSI) has been measured using self-reporting of students' emotions using available affective instruments. This research showed that students were interested in engaging with the SSI topic and writing narratives about the topic. This engagement evoked pride in their work and self-efficacy in completing the task. More recently, student emotion diaries have been used to elicit a wider range of emotional states from students at the end of each lesson. Students identify specific emotions experienced during each lesson, noting when these were experienced so that follow-up microanalyses of video recordings of these events can be undertaken.

Interview studies (e.g., Zembylas 2004) have reported both positive and negative emotions experienced by science teachers. For example, science teachers have reported experiencing such emotions as joy, despair, delight, frustration, and hope. Positive emotional experiences typically were derived from communicating a vibrant, energetic lesson where a sense of humor was maintained. Successful lessons often were those creative and spontaneous lessons that were enjoyable for the teachers and yielded identifiable learning outcomes for the students which collectively strengthened teacher-student rapport (cf. Ritchie et al.). Interview studies also have been helpful in understanding how emotions affect teacher identity. Unsurprisingly, pleasant emotions reinforce a teacher's professional identities and unpleasant emotions destabilize or threaten a teacher's identities. Turner (2007) invokes the theoretical construct of *facticity* to help explain the relationship between emotion and identity. Facticity is the transactional need for people to feel they experience a common world with others in an encounter. When an individual's need for facticity is met, the positive emotions that are aroused reinforce his/her identities, yet negative emotions that threaten identities are experienced when facticity is not realized.

Despite inconsistent outcomes from psychology research investigating possible links between science conceptual change and positive emotions, recent advances in neuroscience have shown that emotions overlap mental processes in controlled laboratory tasks. This blurring between cognition and emotion suggests that learning has as much to do with cognition as emotion. Guided by such an integrated view of learning, teachers are likely to engage students imaginatively where science concepts come to life, where they become real, meaningful, and filled with emotion (Rosiek and Beghetto 2009). As research on emotions matures, innovative methods for measuring emotions could provide much needed insight into learning science in emotionally filled classrooms.

Cross-References

- ▶ Dialogic Teaching and Learning
- ▶ Engagement with Science
- ▶ Imagination and Learning Science
- ▶ Socioscientific Issues

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Empirical Research

▶ Evidence-Based Practice in Science Education

Empiricism

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Keywords

Analytic/synthetic; Constructivism; Perceptions; Propositional perception; Reductionism; Scientific revolution; Seeing as/seeing that

Empiricism is a part philosophical and part psychological doctrine about the origin (psychology) and evaluation (philosophy) of ideas and concepts. At an everyday level, empiricism maintains that "there is nothing in the mind but that comes from the senses; and ideas or propositions are true in as much as they conforcprm to the evidence of the senses." At a more sophisticated level, empiricism is an epistemological doctrine about the formulation and truth testing of claims, propositions, hypotheses, and theories in all branches of inquiry – mathematics, psychology, social science, history, and so on.

Empiricism has for centuries been an influential doctrine about knowledge-seeking inquiry into the natural world; it has long been an influential philosophy of science since Aristotle's refutation of Platonic rationalism. Understandably, over its 2,500-year history, the doctrine has waxed and waned in response to philosophical challenges. Since the Scientific Revolution its main challenge has been to reconcile itself with modern, post-Galilean science, so much of which seems to contradict its core convictions.

It is important for science teachers to appreciate just what is living and what is dead in the empiricist tradition because debates about it have dominated philosophy of science and thus provide the philosophical background or context for science teachers' own understanding of the discipline they are teaching. Further, empiricism has also had remarkable wider educational and pedagogical impacts. This can be traced from the time of John Locke's 1693 *Thoughts Concerning Education* with its famous (but now mostly infamous) metaphor of the mind as a *tabula rasa*, through to B.F. Skinner's mid-twentieth-century accounts of language learning and subject-matter teaching in which he describes the goal of science teachings as simply "successful behavior in the environment" because such behavior is what is meant by knowledge. And in the current period, the empiricist tradition can also, surprisingly, been seen as providing the psycho-philosophical foundation for much of constructivist pedagogy and theory, especially in the version championed by the late Ernst von Glasersfeld.

Origins

For the pre-Socratics, Democritus, Epicurus, and others, sensory evidence or experience – *empeira* – was a requirement or hallmark of claims to knowledge. Aristotle continued this epistemological tradition with his rejection of Platonism. For Aristotle knowledge was not about the sensory input, or what was seen; it was about universal features or principles, but the senses were the "windows" to the world; they were what enabled knowledge of universals; the senses could not be bypassed.

Thomas Aquinas (1224–1274), the enormously influential medieval theologian and philosopher, despite ecclesiastical warnings, continued and built upon Aristotle's realism and empiricism. Concerning the natural world, the mind could only work with experience, which was constituted by sensation and memory of such sensation. This remembered sensation he labeled a *phantasm*; it is what we might call "experience." The crucial point is that there was already a mental element in experience; the epistemologically significant *phantasm* was both sensation and sensory activation, plus memory's "packaging" of this.

British Empiricists

The eighteenth-century trio of British empiricists – John Locke, George Berkeley, and

David Hume – laid down the foundations of modern empiricism. They were all intimately involved with the epochal Scientific Revolution associated in the first instance with Galileo, Huygens, Boyle, and Newton. Locke famously cast himself as an "under-laborer" in Newton's vineyard and saw his chief philosophical task as "clearing away rubbish and weeds" and making intellectual space for the expansion of the New Knowledge.

Within just a few years of Newton's *Principia* being published, Locke published what was in his view the philosophical underpinnings of the New Science – *An Essay Concerning Human Understanding* (1689). Some 80 years later, David Hume adopted and elaborated Locke's psycho-philosophical account of the origin and testing of ideas. Hume referred to the contents of the mind as "perceptions" and said they are divided into two broad classes: impressions and ideas. The former are sensations, feelings, emotions, and others such primitives; ideas are copies or reflections of these primitives. Some ideas are simple copies or reflections – "red," "heavy," "hard," or "tree"; other ideas are compound or aggregates – "red box," "hard tree," and so on. Some compound ideas are fanciful – "diamond box," "weightless tree," or "unicorn." They are fanciful because although the constituents have their origin in simple ideas, there is no impression that the compound can be traced back to; the mind creates the compound from simples, but it is a fanciful creation.

This distinction and causal mechanism provides Hume with the materials for his "philosophical microscope," for the means of examining and separating among the host of ideas entertained by people and cultures those that are "sensible" and those that are "nonsensible." He writes:

> When we entertain, therefore, any suspicion that a philosophical term is employed without any meaning or idea (as is but too frequent), we need but inquire *from what impression is that supposed idea derived*? And if it be impossible to assign any, this will confirm our suspicion. By bringing ideas into so clear a light we may reasonably hope to remove all dispute, which may arise, concerning their nature and reality. (*Inquiry Concerning Human Understanding*, Section II, #17; Hume 1777/1902, p. 22)

Empiricism and the New Science

It seemed obvious that when Hume's microscope was trained upon Newtonian science, many core ideas would be rendered "nonsensible" or fanciful. So "attraction at a distance," "corpuscules," "gravity," "magnetic fields," and so on all supposedly would be placed in Hume's rubbish bin. And the more that science developed, the greater became the number of "fanciful" and "nonsensible" ideas destined to be put in the bin – atoms, electric fields, electrons, and so on.

Contemporary Criticism

Since the 1950s empiricism has been in philosophical retreat. The bugle was blown by Quine when he wrote in his "Two Dogmas" that:

> Modern empiricism has been conditioned in large part by two dogmas. One is belief in some fundamental cleavage between truths which are *analytic*, or grounded in meanings independent of matters of fact, and truths which are *synthetic,* or grounded in fact. The other dogma is *reductionism*: the belief that each meaningful statement is equivalent to some logical construct upon terms which refer to immediate experience. Both dogmas, I shall argue, are ill-founded. (Quine 1951/1953, p. 20)

Wilfrid Sellars closely followed up this critique with his 1956 *Empiricism and the philosophy of mind* paper. The long paper was originally given as three lectures with the title *The myth of the given*. This title conveys the core of the modern argument against empiricism: there is no given, objective, sensory foundation for knowledge of the world, much less for scientific knowledge of the world. Sellars carefully picked apart the psycho-philosophical theory of sensations and ideas that had been elaborated in such detail by Locke, Berkeley, and Hume. Of the supposed foundation of experience, Sellars wrote that:

> For although *seeing that x over there, is red* is an *experiencing* - indeed a paradigm case of experiencing - it does not follow that the descriptive content of this experiencing is itself an experiencing. (Sellars 1956, p. 282)

Sellars' more general point was that experience has to be articulated, described, and conveyed before it has any role in knowledge creation. Ideas or thoughts have to have names or descriptions; and the link between sensation and verbalized idea is simply not automatic, direct, and given as the founding eighteenth-century empiricist trio, and all subsequent exponents of the tradition, thought that it was. As others noted (Hanson 1958), there is a fundamental distinction between *seeing as* and *seeing that*. The former is a visual sensation. The latter is propositional perception: "I see that the apple is red," "I see that the acid reacts with metal," "I see that the stone weighs two kilos," and so on. The structure of propositional perception is "I see that *p*," where *p* is any verbalized proposition. Propositional perception depends on already having words, concepts, and language being part of a community and culture. You cannot see that the acid reacts with metal unless you know what an acid and a metal is (Mandelbaum 1964).

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Enculturation

▶ Acculturation

Engagement with Science

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Within the field of science education, new approaches to teaching and learning science content have emerged (NRC 2012). There has been a shift in the science education community from a focus on supporting the acquisition of formal science knowledge to the current perspective of promoting a culture of scientific literacy through student engagement in scientific inquiry, language, and practices. Student engagement with science in the modern education era emerged primarily from the work of John Dewey. Dewey promoted an approach to learning that allowed students to explore and comprehend their world in ways that fostered deeper understanding. Dewey's move from didactic lectures to participatory models allowed for student engagement in collaborative inquiry practices. His pedagogical approach utilized instructional strategies that embedded content in rich inquiry contexts. This situative learning environment allows the students to gain an appreciation for the content learned in situations where scientific content has value and meaning.

Dewey's notion of participatory practices serves as the basis for situative learning theories such as activity theory (Vygotsky 1978) and situated cognition (Brown 1989). These two theoretical perspectives are premised on the fundamental inseparability of learning and activity from the context in which that activity takes place. This viewpoint stands in opposition to traditional curriculum frameworks where knowledge is separated from experience, therefore fragmenting students' learning. When the student's learning is fragmented by a focus on subject matter rather than on their hands-on experience, a gap is created between the student's interest and the subject matter. If learning is viewed in this fragmented, fixed, and ready-made approach, then too much attention will be directed towards outcomes and the process of learning. By using socially constructed methods and activities, students will be able to connect their interests to their learning in order to create their own authentic engagement with science. What is important for engaged learning, at least in part, is the attention placed on the process. This process can be aided by a diversified curriculum that advocates a problems-based, core-curriculum, or project-based approach. By starting with central, driving questions, students can approach problems in distinct ways that are based upon their own unique interests and needs. This structure creates a learning environment where process and content are not fixed, nor are they an end onto itself. These types of inquiry-based learning methods allow for dealing with changes within the environment or society in a scientific, problem-solving manner, thus developing students who are better prepared and more engaged in the learning of science.

When translating these theories into practice, the affordances of leveraging technology become apparent. Engaging students in complex phenomenon is challenging. The following examples demonstrate the integration of these theories utilizing technologies in rich learning contexts to engage twenty-first-century learners. In the work of Barnett and colleagues (2011), students engaged in a street tree inventory as part of a biodiversity field studies project. By creating an inventory that was continuously updated to reflect changes to the tree canopy of a large urban area, students were able to engage in a scientific inquiry of the natural resources within their own community while learning GIS technology and modeling skills that are utilized by the scientific community. In this instance, science curricula were contextualized in order to meet local needs and create opportunities where not only was science content learned, but the language and ways of inquiry and engagement in science were present. Students become active participants, in projects like this, that can help to set their own learning goals in relation to the challenges embedded within the project. This allows for the development of meaningful engagement as the students are immersed in real-world, complex problems.

Computer simulations and games provide another mechanism to immerse students in the study of abstract, complex scientific concepts (Clark et al. 2009). The affordance of digital technologies allows for the immersion of students in worlds that represent specific scientific phenomenon. The immersive nature of gaming provides students with experiences that allow them to draw upon thinking about scientific concepts, using intuitive knowledge during play to interpret complex problems. By leveraging the affordances of digital gaming environments, educators can increase engagement and foster deeper learning as the students engage in recursive and critical game play, whereby hypotheses are generated, plans and strategies are developed, observations are created, and ultimately hypotheses are adjusted based upon game play (Clark et al. 2009). Games that are well designed allow students to build upon intuitive understandings of this complex physical phenomenon due to the situated and enacted nature of the environment (e.g., Clark et al. 2009); games also have the potential to support students in integrating their tacit conceptual knowledge with instructed knowledge (Clark et al. 2009). This is accomplished through the specific design of the game that allows students to make choices that affect the state of the models being simulated. Complex scientific content that is represented through tangible, experienced, non-textually mediated representations, games, and simulations may serve to engage reluctant learners in the study of science.

Cross-References

- ▶ Action and Science Learning
- ▶ Assessment of Doing Science
- ▶ Dewey and the Learning of Science

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Engineering and Technology: Assessing Understanding of Similarities and Differences Between Them

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A variety of meanings have been associated with the terms engineering and technology. The definitions for this encyclopedia entry are based on numerous documents produced by national sets of experts. The National Academy of Engineering report, *Standards for K-12 Engineering Education*? (NAE 2010), surveyed standard documents in engineering, technology, science, and mathematics to identify common engineering concepts and skills. The National Assessment Governing Board supported development of the *Technology and Engineering Literacy* (*TEL*) *Framework for the 2014 National Assessment of Educational Progress*. The National Research Council of the National Academies has published the *Framework for K-12 Science Education*, which, along with a draft *Next Generation Science Standards*, integrates engineering ideas and practices with those in science (NRC 2012; Achieve 2012). Definitions of engineering and technology can be culled from these frameworks and standards developed by engineering and science organizations, as well as from standards for engineering and technology for state, national, and international assessments.

The definitions of engineering and technology are the starting points for developing assessments of understanding of the similarities and differences between them. This encyclopedia entry begins with a summary of prominent conceptualizations of engineering and technology. The definitions are followed by descriptions of an assessment framework that can be used to develop and analyze engineering and technology assessments. Descriptions of some potential types of assessment tasks and items to test understanding of the similarities and differences between engineering and technology are provided.

Definitions of Engineering and Technology

Engineering is defined as a systematic and iterative approach to designing objects, processes, and systems to meet human needs and wants. *Technology* is defined as any modification of the natural or designed world developed to fulfill human needs or desires. Technologies, therefore, are products and processes resulting from application of engineering design processes. Technologies also often function as tools and processes used to support engineering design.

Sources of Conceptualizations of Engineering and Technology

Standards for K-12 Engineering Education? The purpose of the National Academy of Engineering report was to survey contemporary frameworks, standards, and practices in engineering to determine if a national set of engineering standards could be proposed (NAE 2010). The report summarized key ideas of engineering and recommended that engineering concepts and processes should be integrated into and linked with contemporary frameworks and standards in science, technology, mathematics, and other disciplines. The report identified a set of the most commonly cited core engineering concepts. The central engineering construct was "design" – understanding and doing it.

Other important concepts included understanding constraints, understanding systems, and optimization. Central skills included modeling, systems thinking, and analysis. In addition, the report emphasized the importance of understanding the relationship of engineering and society and the connections among engineering, technology, science, and mathematics.

Technology and Engineering Literacy (TEL) Framework for the 2014 National Assessment of Educational Progress

The TEL framework is unique in its focus on assessing the interrelationships of engineering and technology. In the framework, technology and engineering literacy is defined as the capacity to use, understand, and evaluate technology as well as to understand technological principles and strategies needed to develop solutions and achieve goals (NAGB 2010). Technology and engineering literacy is divided into three assessment areas, design and systems, information and communication technology, and technology and society. Within design and systems, four subareas of essential knowledge and skills were identified: nature of technology, engineering design, system thinking, and maintenance and troubleshooting.

Principles for the nature of technology expand the scope of common conceptualizations of technology beyond computers and the Internet. The broader view includes every way people manipulate the natural environment to satisfy needs and wants. Therefore, technology includes all the various devices and systems that people make to fulfill some function. The framework lays out key principles for the nature of technology: (1) technology is constrained by the laws of nature; (2) scientists examine what exists in nature, and engineers modify natural materials to meet human needs and wants; (3) technological development involves creative thinking; (4) technologies developed for one purpose may be adapted for other purposes; (5) science, technology, engineering, mathematics, and other disciplines are naturally supportive; (6) the pace of technological change has been increasing; and (7) tools help people to do things efficiently, accurately, and safely. The framework then lays out assessment targets for the nature of technology for grades 4, 8, and 12.

The engineering design subarea in the TEL framework is described as an iterative, systematic process for solving problems. The process begins with stating a need or want and the criteria and constraints of the challenge. Then potential solutions are explored referencing relevant scientific and technical information. Potential solutions are compared, and models and prototypes are constructed, tested, and evaluated to see how they meet the criteria and constraints of the problem. The results of the engineering design process will be technology in the form of either a product or a process. The framework specifies key principles of engineering design and proposes assessment targets for grades 4, 8, and 12. Two additional components of design and systems are systems thinking and maintenance and troubleshooting. For each component, principles are identified and assessment targets for grades 4, 8, and 12 are presented.

The framework also specifies components, principles, and assessment targets for grades 4, 8, and 12 for the prominent technology area of information and communication technology (ICT). ICT is presented as a separate assessment area within technology and engineering literacy because of the central place ICT plays in learning and functioning in school, the workplace, and daily living. ICT subareas to assess include understanding and use of technologies for (1) construction and exchange of ideas and solutions, (2) information research, (3) investigation of problems, (4) acknowledgment of ideas and information, and (5) selection and use of digital tools.

The TEL framework can serve as an important resource for identifying assessment targets relevant for distinguishing between engineering and technology.

Framework for K-12 Science Education and the Next Generation Science Standards

The framework includes engineering and technology as they relate to applications of science. Engineering is used to mean engagement in a systematic design practice to achieve solutions to particular human problems. Technology is used to include all types of human-made systems and processes. Two core engineering ideas are specified. The first is engineering design – how engineers solve problems. The second core idea is understanding of the links among engineering, technology, science, and society. Engineering design is subdivided into three components: (1) defining and delimiting a problem, (2) developing possible solutions, and (3) optimizing the design solution. Links among engineering, technology, science, and society are partitioned into (1) interdependence of science, engineering, and technology and (2) the influence of engineering, technology, and science on society and the natural world. The framework describes grade-band end points for each of the three components.

The *Next Generation Science Standards* provides more specific guidance for assessing engineering design that produces and uses technology (NRC 2013). Performance expectations are presented for the engineering design components. Performance expectations have been developed that integrate the engineering core ideas with cross-cutting concepts such as systems and models and cause and effect and also with science and engineering practices.

Each of the frameworks and standards described above can serve as resources for specifying the similarities and differences between engineering and technology to be assessed. In the following section, the use of a systematic assessment design framework is presented to support the selection or development of assessments.

Evidence-Centered Assessment Design

The focus of this entry in the encyclopedia is on methods for assessing understanding of the similarities and differences between the engineering design processes and the technologies that can both support the design processes and are a result of them. The selection or development of assessments will depend on the purposes of the assessments and the interpretations of the data. An assessment may be intended to provide diagnostic feedback and be used in a formative way to allow adjustments during instruction to improve performance. An assessment may be intended to serve a summative purpose to report on the status of proficiency at a point in time. These purposes will have implications for the criteria used to select, design, or interpret assessments.

A useful framework for understanding the structure of assessments is evidence-centered assessment design (Mislevy et al. 2003). Evidence-centered design is intended to structure an assessment argument. The argument begins with the claim that specified knowledge or skills have been learned. Evidence to support the claim comes from the types of questions or tasks that will elicit observations and performances of the targeted knowledge or skill. Summaries of performances, typically in the form of scores to be reported and interpreted, then complete the argument. Evidence-centered assessment design tightly links the targeted knowledge and skills (student model), with assessment tasks and items to elicit evidence of these targets (task models) and with specifications of how the evidence will be scored and analyzed to report proficiencies (evidence model). The evidence-centered design framework can be used to analyze and evaluate existing assessments or to guide the systematic development of new ones.

The essential first step in assessing student understanding of the similarities and differences between engineering and technology will be to settle on the definitions of engineering and technology and to specify the similarities and differences to be tested. The similar and different features would become the first component of the student model. A second component of the student model would be the cognitive demands or levels of reasoning required. Cognitive demands could range from identifying definitions and lists of similar and different features, to analyzing the features, to evaluating others' identifications of the similarities or differences.

The engineering design process creates plans for developing solutions. Solutions may be tangible artifacts or technologies, such as digital devices or farm machinery. Solutions may also be new or improved technological processes such as more efficient manufacturing procedures or pharmaceutical clinical trials. These solutions are *technologies* that have been developed to address needs in areas of the designed world such as medicine, agriculture, energy, transportation, manufacturing, and construction. Students tend to think of technology in terms of computers and digital technologies, not in terms of the artifacts and solutions engineered in the many other areas of the designed world. Students are expected to understand that there are technologies in all these areas, from pills to plows, plugs, planes, pinions, and pickup trucks. Specifications of the knowledge to be tested will need to decide what students need to understand about the distinctions between the engineering processes, the role of technologies in them, and the technology products. It is likely that such discriminations would be part of a more comprehensive assessment of engineering and technology that would also include understanding of types and functions of representative technologies.

Since engineering is the process, and technology is the product, or a support for the process, the level of cognitive demand is not likely to be very high. Statements of what the student needs to know and the level of reasoning for showing it will become the assessment targets of the student model.

The task model specifies the kinds of contexts, problems, and items that would elicit evidence that the students understood the similarities and differences between engineering design and technology. Simple items could list features of engineering design and technology and have students select the appropriate discriminations. Descriptions of needs addressed by an engineering project producing solutions could include questions to determine that students understood that the solutions, whether new tools or new processes, are technologies. Tasks and items could be designed around scenarios presenting engineering design problems in a range of applied contexts. The overarching problem could be to select and construct engineering processes to use in attempting to solve the problem. Questions about the appropriate supporting technological tools to use and about the resulting solution as a technological advance could be inserted within tasks.

The evidence model would involve determining what kind of scoring and reporting would convey that the student understands the similarities and differences. Specific reports about the similarities and differences assessment target would be needed.

The assessment selection or development can use the framework of evidence-centered assessment design framework to guide analyses of existing tasks and items or to guide the development of appropriate tasks and items. The framework would ask if the knowledge to be tested is clearly specified (student model), if the tasks and items will provide evidence, and if the discriminations have been made, perhaps in a range of applied areas such agriculture, medicine, and manufacturing. The framework would also ask if the scoring and reporting clearly allowed decisions to be made about whether the understanding of the differences between engineering and technology is sufficiently strong. The decisions could then be used diagnostically to inform further instruction or to support a proficiency report. The key to sound assessment is that the assessment argument is clear and supported.

Cross-References

- ▶ Assessment of Knowing Engineering and Technology and Doing Engineering and Technology: Overview
- ▶ Engineering, Assessing Understanding of
- ▶ Engineering Design, Assessing Practices of
- ▶ Science, Technology, and Engineering Interrelationships: Assessment of the Understanding of
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Engineering Design, Assessing Practices of

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Keywords

Engineering design; Framework; Optimization; Systems thinking

Numerous documents produced by national sets of experts offer similar definitions of engineering practices. The National Academy of Engineering report, *Standards for K-12 Engineering Education*? (NAE 2010), surveyed standards documents in engineering, technology, science, and mathematics to identify common engineering concepts and skills. The National Assessment Governing Board supported development of the *Technology and Engineering Literacy (TEL) Framework for the 2014 National Assessment of Educational Progress*. The National Research Council of the National Academies has published the *Framework for K-12 Science Education*, which, along with a draft *Next Generation Science Standards*, integrates engineering ideas and practices with those in science (NRC 2012; Achieve 2012). Definitions of engineering practices can be culled from these frameworks and standards developed by engineering and science organizations, as well as from standards for engineering and technology for state, national, and international assessments.

The definitions of engineering and the design engineering process are the starting points for developing assessments of engineering practices. This encyclopedia entry begins with a summary of prominent conceptualizations of engineering and the outcomes of engineering design – technology. The definitions are followed by descriptions of an assessment framework that can be used to analyze or develop assessments of engineering practices. Descriptions of some potential types of assessment tasks and items to test understanding of the similarities and differences between engineering and technology are provided.

Definitions of Engineering, Engineering Practices, and Technology

In the *Framework for K-12 Science Education*, engineering is defined as the application of science in a systematic design practice to achieve solutions to particular human problems. *Engineering design* is defined as a systematic and iterative approach to designing objects, processes, and systems to meet human needs and wants. The engineering design processes constitute the engineering practices set forth in frameworks and standards documents. Products and processes resulting from application of engineering design practices are technologies. Technologies also often function as tools and processes used to support engineering design practices.

Sources of Conceptualizations of Engineering Practices

Standards for K-12 Engineering Education? (NAE 2010). The report surveyed contemporary frameworks, standards, and practices in engineering to determine if a national set of engineering standards could be proposed. The report summarized key components of engineering and recommended that engineering concepts and processes should be integrated into and linked with contemporary frameworks and standards in science, technology, mathematics, and other disciplines. The report identified a set of the most commonly cited core engineering concepts. The central engineering construct was "design" – understanding and doing it. Other important concepts included understanding constraints, understanding systems, and optimization. Central skills, or practices, included modeling, systems thinking, and analysis.

Technology and Engineering Literacy (TEL) Framework for the 2014 National Assessment of Educational Progress. The TEL framework describes technology and engineering literacy as the capacity to use, understand, and evaluate technology as well as to understand technological principals and strategies needed to develop solutions and achieve goals (NAGB 2010). Technology and engineering literacy is divided into three assessment areas: design and systems, information and communication technology, and technology and society. Within design and systems, three subareas of essential knowledge and skills were identified: nature of technology, engineering design, systems thinking, and maintenance and troubleshooting.

The engineering design subarea in the TEL framework is described as an iterative, systematic process for solving problems. These processes are among the practices of engineering. The process begins with stating a need or want and the criteria and constraints of the challenge. Then potential solutions are explored referencing relevant scientific and technical information. Potential solutions are compared, and models and prototypes are constructed, tested, and evaluated to see how they meet the criteria and constraints of the problem. Two additional components of design and systems are systems thinking and maintenance and troubleshooting. Systems thinking is a way of thinking about devices and situations so as to better understand interactions among components, root causes of problems, and the consequences of various solutions. Maintenance and trouble shooting is the set of methods used to prevent technological devices and systems from breaking down and to diagnose and fix them when they fail. For each of these design and systems components, assessment targets for grades 4, 8, and 12 are presented.

The TEL framework also describes three cross-cutting practices: understanding technological principles, developing solutions and achieving goals, and communicating and collaborating. The framework provides examples of how these practices apply to the engineering design, systems thinking, and maintenance and troubleshooting areas.

Framework for K-12 Science Education and* the Draft *Next Generation Science Standards (NRC 2012; Achieve 2012). The framework includes engineering and technology as they relate to applications of science. Engineering is used to mean engagement in a systematic design practice to achieve solutions to particular human problems. Technology is used to include all types of human-made systems and processes. Two core engineering ideas are specified. The first is engineering design – how engineers solve problems. The second core idea is understanding of the links among engineering, technology, science, and society. Engineering design is subdivided into three components: (1) defining and delimiting a problem, (2) developing possible solutions, and (3) optimizing the design solution. Links among engineering, technology, science, and society are partitioned into (1) interdependence of science, engineering and technology and (2) the influence of engineering, technology, and science on society and the natural world.

The framework also describes the key practices that scientists use as they investigate and build models and theories about the world and the key engineering practices that engineers use as they design and build systems. Science and engineering practices include asking questions and defining problems; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics, information and computer technology, and computational thinking; constructing explanations and designing solutions; and engaging in argument from evidence. The framework describes grade band endpoints.

The draft *Next Generation Science Standards* provides more specific guidance for assessing science and engineering practices. Performance expectations are provided that integrate disciplinary core ideas, cross-cutting concepts, and science and engineering practices for elementary, middle school, and high school.

Each of the frameworks and standards described above can serve as resources for specifying engineering to be assessed. In the following section, the use of a systematic assessment design framework is presented to support the selection or development of assessments of engineering practices.

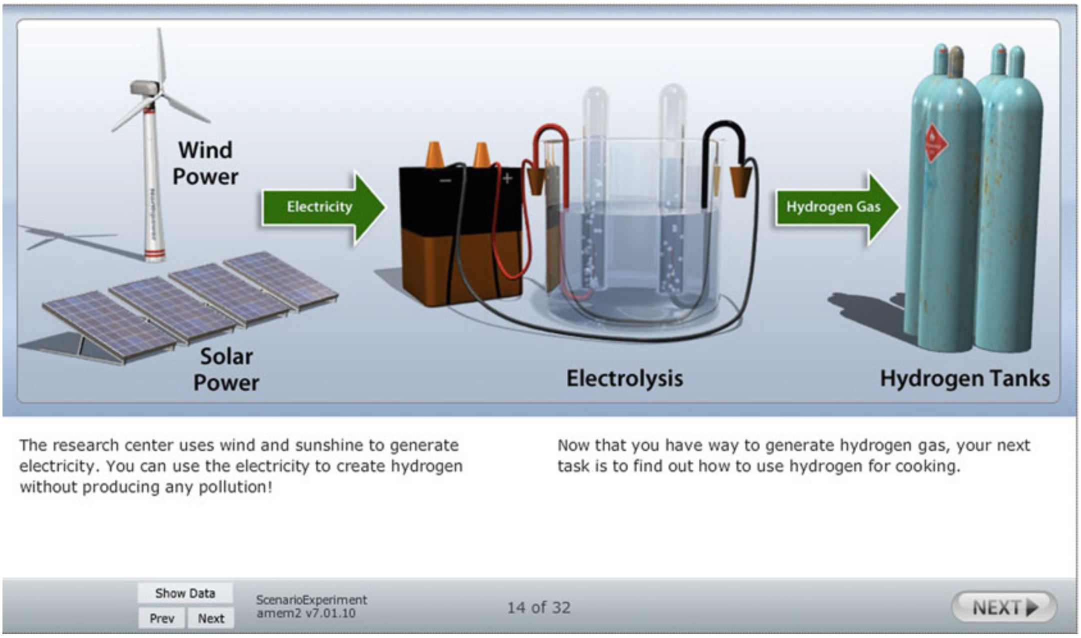
Evidence-Centered Assessment Design

The focus of this entry in the Encyclopedia is on methods for assessing engineering practices. The selection or development of such assessments will depend on the purposes of the assessments and the interpretations of the data. An assessment may be intended to provide diagnostic feedback and be used in a formative way to allow adjustments during instruction to improve performance. Or, an assessment may be intended to serve a summative purpose to report on the status of proficiency at a point in time. These different purposes will have implications for the criteria used to select, design, or interpret assessments of engineering practices.

A useful framework for understanding the structure of assessments is evidence-centered assessment design (Mislevy et al. 2004). Evidence-centered design is intended to structure an assessment argument. The argument begins with the claim that specified knowledge or skills have been learned. Evidence to support the claim comes from the types of questions or tasks that will elicit observations and performances of the targeted knowledge or skill. Evaluations of performances, typically in the form of scores to be reported and interpreted, then complete the argument. Evidence-centered assessment design tightly links the targeted knowledge and skills (student model), with assessment tasks and items to elicit evidence of these targets (task models), with specifications of how the evidence will be scored and analyzed to report proficiencies (evidence model). The evidence-centered design framework can be used to analyze and evaluate existing assessments to determine the coherence of the assessment claims they can support. Evidence-centered design can also guide the systematic development of assessments of engineering practices.

The essential first step in assessing engineering practices will be to specify the practices to be tested. These practices would become the first component of the student model. A second component of the student model would be the cognitive demands or levels of reasoning and complexity of application required. Cognitive demands could range from simple identification of practices being used during an engineering project or selection of practices to be used, to active application of the practices to solve a variety of problems, to evaluating the appropriate use of the engineering practices by others. Importantly, assessment targets would include not only being able to recognize and evaluate practices, but to actually employ them appropriately in a range of engineering contexts in the designed world such as medicine, agriculture, energy, transportation, manufacturing, construction, and academic disciplines.

The assessment task model specifies the kinds of contexts, problems, and items that would elicit evidence that the students understand and can employ engineering practices. For example, in the *Framework for K-12 Science Education* for each of the components of engineering design processes such as defining problems; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics, information, and computer technology and computational thinking; constructing explanations and designing solutions; and engaging in argument from evidence, the assessment could present tasks and items along a progression from recognition of the components in use, to application of them, to evaluation of their use by others. Tasks and items could be designed around scenarios presenting engineering design problems in a range of applied contexts. The overarching problem could be to select and construct engineering processes to use



The research center uses wind and sunshine to generate electricity. You can use the electricity to create hydrogen without producing any pollution!

Now that you have way to generate hydrogen gas, your next task is to find out how to use hydrogen for cooking.

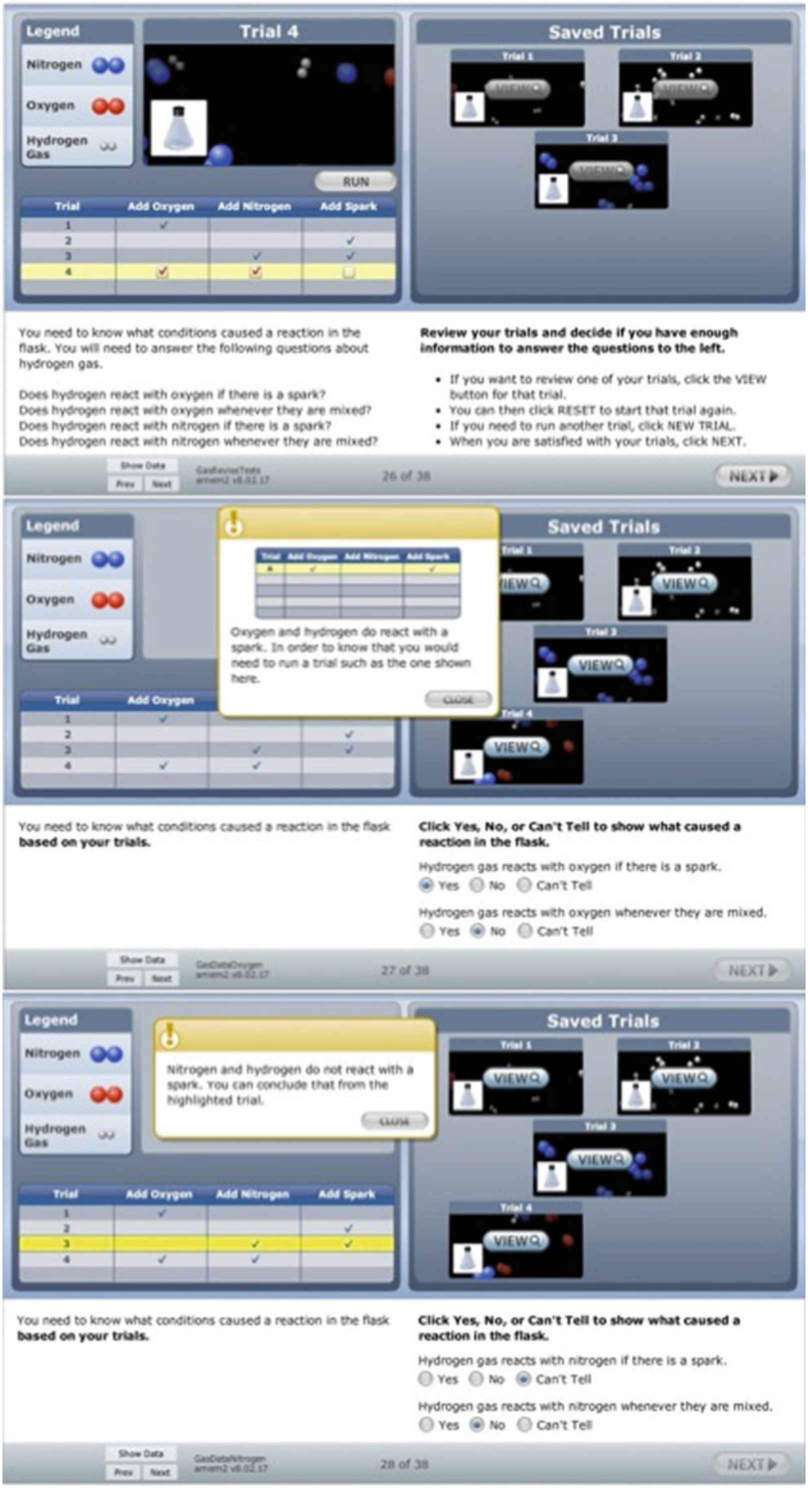
Engineering Design, Assessing Practices of, Fig. 1 SimScientists problem for engineering design: how to use hydrogen for cooking

in attempting to solve the problem. Within tasks could be inserted questions about the appropriate supporting technological tools and processes to use and about the resulting solution as a technological advance.

Technologies are now available to support the design of innovative tasks that allow students to interact with dynamic systems and actively engage in science and engineering design processes. The SimScientists program, for example, has developed suites of simulation-based formative and summative assessments for middle school science units (http://sinscienitsts.org). The assessments are set in scenarios that present a real-world problem to solve. For example, for the atoms and molecules unit, simulation-based assessments have been developed to embed during the unit. The assessment targets focus on understanding the components, interactions, and emergent behavior of a system and the science and engineering practices for studying them or developing a solution. The embedded assessments provide feedback and graduated coaching on science content and the science and engineering practices as well as progress reports to be used as formative assessment. The end-of-unit simulation-based benchmark assessments present a new scenario and problem to be solved. The benchmark assessments are summative measures of proficiency, so no feedback and scaffolding are provided.

Figure 1 shows a problem set for the atoms and molecules embedded assessments in a research center in Antarctica. Students are given a series of problems around how to make the research center more sustainable given the available resources and tools. For example, students try to figure out the best process for creating hydrogen gas for cooking. The students must apply their scientific understanding about atoms and molecules and their interactions to determine the best cooking method.

The sequence of screens in Fig. 2 focuses on assessing the design of investigations. Students



Engineering Design, Assessing Practices of, Fig. 2 Design, conduct, and interpret investigations to solve a real-world problem

Trial	Add Oxygen	Add Nitrogen	Add Spark
1	✓		
2			✓
3		✓	✓
4	☑	☑	☐

You need to know what conditions caused a reaction in the flask. You will need to answer the following questions about hydrogen gas.

Does hydrogen react with oxygen if there is a spark?
Does hydrogen react with oxygen whenever they are mixed?
Does hydrogen react with nitrogen if there is a spark?
Does hydrogen react with nitrogen whenever they are mixed?

Review your trials and decide if you have enough information to answer the questions to the left.

- If you want to review one of your trials, click the VIEW button for that trial.
- You can then click RESET to start that trial again.
- If you need to run another trial, click NEW TRIAL.
- When you are satisfied with your trials, click NEXT.

Oxygen and hydrogen do react with a spark. In order to know that you would need to run a trial such as the one shown here.

Trial	Add Oxygen		
1	✓		
2			✓
3		✓	✓
4	✓	✓	

You need to know what conditions caused a reaction in the flask **based on your trials.**

Click Yes, No, or Can't Tell to show what caused a reaction in the flask.

Hydrogen gas reacts with oxygen if there is a spark.
● Yes ○ No ○ Can't Tell

Hydrogen gas reacts with oxygen whenever they are mixed.
○ Yes ● No ○ Can't Tell

Nitrogen and hydrogen do not react with a spark. You can conclude that from the highlighted trial.

Trial	Add Oxygen	Add Nitrogen	Add Spark
1	✓		
2			✓
3		✓	✓
4	✓	✓	

You need to know what conditions caused a reaction in the flask **based on your trials.**

Click Yes, No, or Can't Tell to show what caused a reaction in the flask.

Hydrogen gas reacts with nitrogen if there is a spark.
○ Yes ○ No ● Can't Tell

Hydrogen gas reacts with nitrogen whenever they are mixed.
○ Yes ● No ○ Can't Tell

are asked to conduct an experiment to determine if hydrogen gas reacts with either nitrogen or oxygen gas, in the presence or absence of a spark, to produce a flame. This is part of the scenario in which students are investigating the use of hydrogen gas as a fuel source for a cook stove. Students can conduct trials by selecting different variables, running the trial, and then saving the trial (top screen). Saved trials can be watched at any point during the task. Once students have completed their trials, they must form conclusions using evidence from their trials. Students are given feedback on their conclusions. If a student makes an incorrect conclusion because they did not run a trial that would have provided the necessary information, then the feedback illustrates what that trial would look like (middle screen). If a student makes an incorrect conclusion based on a trial they did run, then the feedback highlights the trial and coaches the student on how to correct the conclusion (bottom screen).

These formative assessments for atoms and molecules are followed by a simulation-based benchmark assessment to provide a summative report of student proficiency on the assessment targets. The summative assessment presents a new real-world problem, determining potential safety dangers from a chemical spill. Such simulations can support the design of sequences of interactive assessment tasks allowing students to engage in science and engineering practices to solve an authentic problem.

The evidence model of assessments of engineering practices would involve determining what kind of scoring and reporting would convey that the student understands and can apply and critique applications of engineering practices that are employed in a variety of contexts and problems. Assessment reports on progress to be used formatively during instruction would be finer grained than reports of proficiency on the specified assessment targets.

The assessment selection or development can use the framework of evidence-centered assessment design framework to guide analyses of existing tasks and items or to guide the development of appropriate tasks and items. The framework guides asking if the knowledge to be tested is clearly specified (student model), if the tasks and items will provide evidence if the targeted understanding and applications of engineering practices have been made, perhaps in a range of applied areas such agriculture, medicine, and manufacturing. The framework would also ask if the scoring and reporting clearly allowed decisions to be made about whether the understanding and applications of engineering practices are sufficiently strong. The decisions could then be used diagnostically to inform further instruction or to support a proficiency report. The key to sound assessment is that the assessment argument is clear and supported.

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- ▶ Assessment of Knowing Engineering and Technology and Doing Engineering and Technology: Overview
- ▶ Computer-Based Assessment
- ▶ Technology, Assessing Understanding of

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Engineering, Assessing Understanding of

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The definitions of engineering for this encyclopedia entry are based on numerous documents produced by national sets of experts. The definitions of engineering are the starting points for developing assessments of understanding of it. This encyclopedia entry begins with a summary of prominent conceptualizations of engineering. Descriptions of some potential types of assessment tasks and items to test understanding of engineering are provided.

Definitions of Engineering

Engineering is defined as a systematic and iterative approach to designing objects, processes, and systems to meet human needs and wants. The products and processes resulting from application of engineering design processes are technologies. Technologies also often function as tools and processes used to support engineering design.

Sources of Conceptualizations of Engineering

Standards for K-12 Engineering Education

The report surveyed contemporary frameworks, standards, and practices in engineering (NAE 2010). The central engineering construct was "design" – understanding and doing it. Other important concepts included understanding constraints, understanding systems, and optimization. Central skills included modeling, systems thinking, and analysis. In addition, the report emphasized the importance of understanding the relationship of engineering and society and the connections among engineering, technology, science, and mathematics.

Technology and Engineering Literacy (TEL) Framework for the 2014 National Assessment of Educational Progress

Three main assessment areas were specified: design and systems, information and communication technology, and technology and society (NAGB 2010). Within design and systems, three subareas of essential knowledge and skills were identified: nature of technology, engineering design, system thinking, and maintenance and troubleshooting.

Engineering design is described as an iterative, systematic process for solving problems. The process begins with stating a need or want and the criteria and constraints of the challenge. Then potential solutions are explored referencing relevant scientific and technical information. Potential solutions are compared, and models and prototypes are constructed, tested, and evaluated to see how they meet the criteria and constraints of the problem. The framework specifies key principles of engineering design and proposes assessment targets for grades 4, 8, and 12. Two additional components of design and systems are systems thinking and maintenance and troubleshooting. For each component, principles are identified and assessment targets for grades 4, 8, and 12 are presented.

Framework for K-12 Science Education and the Next Generation Science Standards

The framework (NRC 2011) and standards (NRC 2013) include engineering as it relates to applications of science. Engineering is used to mean engagement in a systematic design practice to achieve solutions to particular human problems. Two core engineering ideas are specified. The first is engineering design – how engineers solve problems. The second core idea is understanding of the links among engineering, technology, science, and society. Engineering design is subdivided into three components: (1) defining and delimiting a problem, (2) developing possible solutions, and (3) optimizing the design solution. The framework describes grade band end points for each of the three components.

The *Next Generation Science Standards* provide more specific guidance for assessing engineering design. Performance expectations have been developed that integrate the engineering core ideas with cross-cutting concepts such as systems and models and cause and effect, and also with science and engineering practices.

Each of the frameworks and standards described above can serve as resources for specifying the engineering concepts to be assessed. In the following section, the use of a systematic assessment design framework is presented to support the selection or development of assessments.

Assessment Methods

Reference to the varying definitions and contexts of engineering can provide the bases for core engineering concepts to be tested. The assessments of understanding engineering concepts may vary the cognitive demands or levels of reasoning required. Cognitive demands could involve simply identifying definitions and lists of engineering design components. More demanding would be to require analysis of the design process components in descriptions of engineering projects occurring in the multiple areas such as agriculture, manufacturing, or medicine. Assessments of understanding could also ask for evaluations of applications of the engineering design processes in multiple contexts. Scoring and reporting of responses to these types of tasks and items would then provide data that could be used diagnostically to inform further instruction or to support a summary proficiency report.

Cross-References

- ▶ Engineering Design, Assessing Practices of
- ▶ Engineering and Technology: Assessing Understanding of Similarities and Differences Between them
- ▶ Science, Technology, and Engineering Interrelationships: Assessment of the Understanding of
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Environmental Education and Science Education

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Keywords

Environmental Education

Over the past half century, environmental education (EE) has evolved as a field of professional practice in response to widespread sociocultural concerns about an increasingly serious array of environmental problems. Historically, public awareness and concern grew in parallel with accumulating scientific evidence of incipient ecological degradation, population-resource issues, and a broadening range of threats to the quality of life and the sustainability of ecosystems. It seems no mere coincidence that ecological science expanded during this time and gained credibility within the academy. In 1969 the first issue of the *Journal of Environmental Education* provided educational coherence to assorted environmental interests in publishing definitional statements for a new interdisciplinary field and in articulating the need for a new environmental ethic and alternative/critical approaches to education, curriculum, and pedagogy based on promoting fundamental changes in human attitudes, relations, and actions. In 1972 a United Nations Declaration on the Human Environment (Stockholm Conference) gave conservation educators, natural resource professionals, and people interested in nature study and outdoor education a common purpose in constructing arguments for inclusion of environmental problems and issues within formal education. On the surface, the history of EE seemed a natural consequence of circumstance.

Less officially, EE has emerged amidst tangled webs of educational responses to environmental issues with perspectives ranging from technical interests concerning appropriate curriculum, pedagogy, and learning outcomes to socially critical approaches promoting interdisciplinary and experiential understandings and practices emphasizing socio-ecological justice. Nothing less than basic reform of the way societies looked at socio-environmental problems and engaged in decision making, it was argued, could alleviate environmental problems of a deteriorating planetary life support system. Whether major responsibility was leveled at the point source of the problem or more generally at societies at large, education systems were targeted as having a key role to play. The mixed rhetoric of environmentalist positionings was reflected in early definitions of EE constructed by the International Union for the Conservation of Nature and Natural Resources (IUCN) and consolidated into a global framework of goals and guiding principles from UNESCO-based conferences in Belgrade and Tbilisi in the mid-1970s. Accordingly, by definition, EE was aimed at producing a citizenry knowledgeable concerning biophysical and sociocultural environments, capable of recognizing values and clarifying concepts concerning those environments, and committed to developing the skills and attitudes necessary for people to work individually and collectively (politically) toward solutions to environmental problems. Many national and regional formulations of EE soon emerged and were adapted to reflect local interpretation of these global goals, all intended to stimulate human responsibility for maintaining and improving the quality of the biosphere (see Palmer 1998).

These official and unofficial activities raised the profile of EE during the 1980s and led to the formation of UNEP (United Nations Environment Programme) thereby establishing a credible international base for dialogue and exchange of curriculum materials. Initially, resources came from rapidly expanding national EE organizations in the USA, Britain, and Australia and these often served as templates for local curriculum development. The importance of international exchanges (via, e.g., the UNESCO CONNECT newsletters) is illustrated by the sharp focus on social processes of community problem solving and decision making that extended beyond the traditional domain and processes of science. In essence, the curriculum and the pedagogy attempted to translate knowledge acquisition into action-oriented processes of change. It was argued that appropriate environmental knowledge, attitudes, and skills could only assume their full significance in contact with real social problems of the environment. It was during this time that forms of behaviorism and instrumental thinking in education were criticized by many within the environmental education community. At international levels, these activities foreshadowed both successes and critiques of EE in the construction of a global environmental component to personal and social ethics in the reform of educational processes and systems (Fensham 1978).

It is important to understand the nature of EE as representing a spectrum of theoretical positions that range from traditional forms of school activities such as schoolyard naturalization, recycling activities, litter patrols, nature walks, and water quality monitoring to forms of critical pedagogy and political activism. Obviously, a -rhetoric-reality gap was to be expected where the socially critical and political action goals of EE could not be realized within existing educational discourse. The spectral tension was reflected in ongoing debate concerning whether or not various forms of EE could find their way into the existing educational systems where whole-scale change seemed unrealistic. Just as there are streams of thought within environmentalism, so EE and EE research have been confronted by different ideologies underlying different currents (Sauvé 2005), visions, and means to change. Several typologies have been constructed to represent the array of arguments for and against development of students' knowledge of political-legal processes in advocacy of particular political positions and/or participation in activist activities. Although EE has often entered the school curriculum through science education, the EE literature has struggled to interpret how the social-political nature of human-environment issues can receive serious consideration among broader social, economic, and political dimensions of science, society, and environment. Thus, it is debates about issues of social and educational values, decision making and action skills, degrees of activism, and interdisciplinarity that have complicated relations within EE itself and between science education and EE.

As EE theory evolved through the 1980s and 1990s, fundamental pedagogical differences between EE and science education became more obvious and created tensions/resistances among contending views about students' active participation in learning, firsthand experiences in natural and built environments, investigation of issues in community and industrial practices, critical thinking, and values clarification skills, as these impacted traditional schooling practices. During this time many curriculum resources were developed promoting environmental issues' investigation, water education for teachers, and animal, plant, and ecosystem studies. Some of these tended toward more formal environmental studies and others the value of aesthetic experiences in natural environments. Differences between science education and EE at curricular levels were articulated within the literature as differences of worldview in intent and practice. Despite impetus from international events, such as the World Conservation Strategy (1980), "Tbilisi Plus Ten" (1987), and Brundtland World Commission on Environment and Development (WCED) (1987), at practical levels, it was the critical self-examination of the goodness of fit between EE (with environment emphasized), ESD (Education for Sustainable Development), science education, and schooling that generated interest.

In each of these discussions, education was considered as a complex construct with stakeholders across many organizations – international and national, governmental and nongovernmental, formal/nonformal, and public and private. Together they formed clusters of interacting systems where relationships varied among cultures, countries, and regions so that any overview is problematic. The educational community whose support the UN was calling for represented those most concerned with inadequacies of environmental science and environmental studies, as well as definitions of environmental learning and environmental literacy (often extending concepts of scientific literacy into the social sciences). The point of all of this was manifest in different conceptualizations of Education for Sustainable Development (ESD) that proved vulnerable to quite diverse interpretations arising from different worldviews, thus presenting practitioners with problems of interpretation and funders with concerns of authentication. Like much of formal education, EE, ESD, and science education have been caught up in a slide away from education's liberal origins toward a vocational-managerial route. Whether this concept of education is enough is the subject of a wider-ranging critique of the current discourse of education. Within EE, Stevenson's (1987) paper perhaps best illustrates persistent major contradictions in purpose and practice between the socially critical and political action goals associated with the contemporary philosophy of EE and traditional practices in schools which emphasized assimilation of factual knowledge as solid foundation for future application.

These concerns, however, mainly trouble people in wealthier, developed countries. In many other places, environmental and socioeconomic factors are inseparable in people's lives. National strategies prepared on Western models offered little to address local needs and give insufficient attention to indigenous life and culture. There are deficiencies that can be ascribed to failure in perception of the whole system, lack of leadership, poor support by societies, and differing points of view to the point where education is an almost-forgotten priority. From the time of the Brundtland Report, ideological conflicts within environmental movements and within EE itself were brought into sharp relief as political debates about direction and practice. Commitments from government officials in many countries revealed a mix of EE and ESD ideas in cross-curricular themes or dimensions of scientific literacy in science education goal statements (e.g., STSE – Science, Technology, Society, Environment). There remains a significant point of contestation within diverse conceptualizations of the relationship of EE and ESD within the literature of EE and science education. While movements toward school-based curriculum, social learning, critical and creative thinking, and community-oriented schooling have been consistent with EE, the confusing rhetoric of ESD was sustained in the 1992 global UN Conference on Environment and Development – the Earth Summit – in Rio de Janeiro, Brazil. The resulting Agenda 21 contained 27 principles for sustainability intended to provide a renewed base for international cooperation and to add legitimacy to and grounding for renewal of EE/ESD in national/local curriculum.

What should be recognized in the activities of the 1990s is how, according to many environmental educators, agencies of the UNEP, IUCN, and WWF changed the language and thus the discourse both in the international goals and in their translation into principles of curriculum development. What should also be recognized is how the parallel forum at the Earth Summit, for representatives of NGOs and educators from around the world, produced guidelines for EE that reaffirmed the values-based and ethical and socio-politico-cultural nature of EE. While ESD retained "official" credibility and provided momentum for public notions of "sustainable development," environmental educators viewed the new discourse of ESD as discursive appropriation of resistance in the politics of environment and development. And so, in spite of these theoretical tensions within the EE/ESD community, in one way or another EE continues to be the "elephant in the room" in debates about the place and value of social-environmental issues in science education.

EE has reached an interesting crossroads. At a time when environmental issues have gone global and are increasingly part of public conversation, government funding is decreasing in both education and environment sectors. And despite credible research from inside and outside the field on the value of EE, changes in daily life are mostly invisible within economies of scale, political hegemony, and the creation of doubt about the certainty of environmental issues, even when grounded in science-based evidence. What is interesting is the persistence of those, both within and outside EE, who continue to challenge the ethics of the status quo in education and in societies from an emerging base in socio-ecological education. The arguments are becoming more thoughtful and philosophically articulate. For example, while many science educators continue to resist forms of values-based political advocacy on grounds of scientific neutrality, environmental educators argue that ethical values are in fact implied by natural facts. Rather than get caught in disputes about scientific evidence per se, they recognize that this naturalistic fallacy may represent the most significant challenge to attempts to ground environmental policy solely within scientific fact. Increasingly many science and environmental educators publicly acknowledge the idea that, while science remains a sound base for knowing about the natural world, it is not sufficient for normative judgments about what best to do. However, the extension of this argument into science teaching remains one of the most vexing problems for environmentalists and environmental educators. Thus, it is this fact-value gap that remains as one of the key challenges in easing the remaining tensions between science education and EE.

EE has come a long way from visions of converting people through behavioral change to inspiring people to expand their thinking, their consciousness, and their ethical positioning; from awareness and understanding of various worldviews to socio-critical forms of action and activism; and from assumptions of language transparency to deconstruction of traditional educational discourses. Much, however, remains to be done. Emerging genres of inquiry have led to a methodological expansion that provides numerous openings, as well as challenges, in both EE and science education. Interdisciplinarity, as a means to the fact-value and aesthetic, ethical, and political "normativities" of the field, remains a challenge. Thinking has broadened as part of larger pedagogical engagements with social and cultural issues and ethico-political processes, but the transition from anthropocentric to ecocentric ethics is incomplete. And while improved theoretical connections to matters of social and environmental justice are evident in the literature of both fields, bringing indigenous and marginalized voices to interface remains inadequate at many levels. Critical socio-ecological educators, ecofeminists, and cultural sociologist and geographers would move further along the path to break free of the discursive limits of sustainable development that seems to privilege business as usual within dominant social models of economic growth and development. Amidst this diverse set of onto-epistemic positions, we find a continuously evolving field where an increasing variety of forms of EE and ESD act separately and in conjunction as socio-ecological and socio-material forms of practice alongside what have become "traditional" embedded practices of EE as "little added frills" to the science curriculum.

In effect we can see why both the practical and theoretical ideas that drive EE have increasingly diverged from those that underpin traditional forms of science education most common in schools. Despite tensions within the field, EE tends toward changing school discourses-practices, whereas the science education literature tends to be less critical of, and thus complicit in, traditional school practice. While exceptions, such as those concerning ecological, cultural, and indigenous knowledge forms, have an increasing presence within the literature of science education, school practice remains the same. Emphases in school science praxis that actively engages the values and ethics of caring, firsthand experiences in natural settings, and interdisciplinary investigation of socio-environmental issues as well as concepts of social and ecological or environmental justice form part of a different onto-epistemic frame than that which currently drives schooling and most school science. Issue-based, problem-centered, community-integrated student activity, conceivable in senior science, goes only part way toward the political action component that has characterized EE goals since its inception. Most environment-related activity seems to depend on the efforts of talented enthusiasts at primary and junior science levels. However, it is also the case that in some countries EE has evolved to fit sociopolitical contexts influenced by ESD frameworks, often governed by national standards. In fact, there is evidence of a widening gap between more traditional liberal approaches to EE/ESD and those EE approaches intended more for purposes of socio-ecological transformation. It seems ironic that even in countries that take environment as a legitimate social concern, when translated into education policy, EE/ESD remains peripheral, as a disjuncture of knowledge forms and pedagogical assumptions concerning those educational qualities that would expand scientific literacy into environmental literacy.

From a science curriculum perspective, science educators who challenge the authority of traditional educational assumptions often align their arguments using dimensions of EE acknowledged as adding relevance and meaning to their programs. Recent literature in science education contains convincing arguments from those who would transform education to align with goals of social (and environmental) justice. Many science educators are beginning to consider how democratic political processes in respect of socio-ecological education may enhance their relevance and credibility with students. Research in science education and EE is increasingly implicated in the evolution of both fields as researchers have learned how to diversify their methodological and theoretical perspectives across a complex of onto-epistemic positions. Research studies from many countries report on the potential of intertwining social and environmental issues of gender, class, race, and colonization within interdisciplinary frames.

In parallel with these transformations in inquiry, both fields are more likely to encourage active engagement of young people in issues that directly implicate crucial sociocultural dimensions of science education and associated research activity. In these transitions sociocultural dimensions of education have become an important theme in research and have come to occupy major strands or themes at (inter)national symposia and conferences.

Beyond these commonalities, critical environmental educators and researchers are currently active in addressing major challenges of this complex of sociocultural and socio-scientific ideas within the curriculum and pedagogy of teacher education. And despite efforts to recast these ideas in goal-change rhetoric, often framed as ESD, EE has developed strands of inquiry in critical pedagogy and activism, ecofeminism, and poststructural perspectives that raise fundamental questions about the role of discourse and power in the formation of identities. Given that social and educational systems are already enacting dominant cultural discourses and that teachers who follow the curriculum cannot avoid inculcating particular values, perhaps the role for critical EE is best performed in creating educational conditions for processes of critical-ethical thought and debate and in encouraging active student learning that encourages and engages young people in critical appraising and valuing multiple perspectives? This, in turn, may help people to work across socio-ecological as well as disciplinary boundaries. The point here is that it takes forms of praxis grounded in views of the social world that cannot ignore human qualities such as embodied emotions, beliefs, and values, as well as insights from a wide range of sensibilities that are crucial to human thought, to transform rather than simply reproduce both educational and socio-ecological conditions. Payne's evolving (Payne 2006) work on a critical ecological ontology for inquiry represents this difficult task in curriculum and pedagogy of sorting and conceptualizing these ideas within deeper overarching frames that can assist the field in making sense of an amalgam of positions. However, without the hard labor of engaging the practical-theoretical gaps that characterize both science and environmental education, EE continually risks fragmentation.

Perhaps because science education is an established school subject, where forms of scientific literacy provide goal structure, there has been less obvious engagement with fundamental (onto-epistemic) challenges to disciplinary structures. It would seem that the time is coming when socially critical and interdisciplinary positions that focus on community problem solving and decision making will need to be addressed as issues of the propositional school curriculum. Potentially there is a strong role for science education here. It is interesting that recent changes proposed in science education (partly in response to young people's interests in technology and media, their patterns of communication, and their concerns about the relevance of science to real-life situations in local environments) tend toward socio-ecological forms of education from a variety of inter- and intra-cultural perspectives. It is in these kinds of spaces, rather than traditional school subjects, that both science and environmental educators can find openings to engage socio-scientific and sociocultural positionings within different forms and levels of curriculum and pedagogy. Just as science education has worked to broaden interpretation of forms of scientific literacy, environmental educators have begun to move, on a somewhat broken front, beyond the sedimented discourse of UNESCO ESD rhetoric, to reengage in critical orientation to change. While this less stable post-critical thinking about curriculum and pedagogy may be disconcerting within traditional sectors of both environmental and science education, it is considered as a state of health by those who value levels of tension within fields where critically reflexive discourses-practices can lead to change.

Recently, within the EE literature, diverse theoretical perspectives confront and complement one another within broad frames of "ecological" sustainability. These perspectives represent a range of philosophical/paradigmatic positionings in respect of both environmental and educational politics and values. For example, many environmental educators now position themselves within sociocultural debates that can accommodate knowledge from various sources, including the social as well as the natural sciences. Knowledge and affect are recognized as useful if not limited in providing insight into the problems of human-environment and culture-nature relations, and as necessary in learning how to understand where and how to focus educationally. Although approaches are increasingly diverse and often reflect the legacy of privileged conceptions, particularly in EE research, the field has moved to engage debates from a wider range of cultural-interpretive, critical, and post-critical perspectives. Beyond these spaces, EE theorists and researchers have begun to explore theoretical perspectives in terms of the process of subjectification, that is, how people have come to construct their environmental identities.

As is now evident within the science education literature, researchers have become aware of the contested nature of ways of knowing (including the scientific) as part of larger onto-epistemic and methodological framings/positionings. Such insight may eventually make it possible for teachers and their students to work with and as inquirers to confront their own notions and ideas about the way the world works and how that implicates reconceptualization of teaching and learning. In reading the hard scholarship found in highly rated journals, we might re-imagine fields of science education and EE in terms of their possibilities in creating conditions for the counternarrative work needed to challenge taken-for-granted cultural discourses and official knowledge. In performing such a postcritical role, each field has attracted a range of scholars and educators who are used to working in uncomfortable spaces. These people accept that they are prone to the kind of critique necessary in pedagogical and theoretical work that crosses traditional boundaries and pushes educators to explore socially critical pedagogies, cultural geographies, and new ways of thinking and doing education.

The kind of critical-thinking and decision-making skills expected of young people today makes it impossible to ignore socio-scientific and socio-ecological justice issues across disciplines and cultural boundaries. If educational goals are intended to engage young people in ways to learn how to participate in democratic processes, it seems appropriate to create educational programs that provide young people with those kinds of experiences that can lead to action. Many environmental educators and a growing number of science educators seem to agree on the importance of expanding or transforming educational practice by invoking new pedagogy arrangements where questions of socio-cultural-political-critical thinking are generated with students as active participants, whether in community or in web-based activity in social media. Whether science education and EE can evolve into a field of professional praxis where people can educationally engage their personal-social-environmental subjectivities in critical explorations of social-environmental issues remains to be seen. Whether, as new pedagogical arrangements are exchanged between educational theory and practice, the old gap may be broached with the potential to make a difference seems to provide a call for compelling action within both fields.

Cross-References

- ▶ Ecojustice Pedagogy
- ▶ Environmental Teacher Education
- ▶ Poststructuralism and Science Education
- ▶ Science for Citizenship
- ▶ Socio-Cultural Perspectives and Characteristics
- ▶ Socioscientific Issues

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Environmental Teacher Education

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Keywords

Environmental Education

Introduction

Environmental Teacher Education (ETE) was established as a valid and necessary area of professional preparation and development during the 1970s. Pioneering efforts by UNESCO-UNEP sought to define broad-based educational parameters for environmental education (EE), and as EE was taken up in a range of curriculum development initiatives, implications for ETE were soon drawn out. From the outset, key drivers of ETE have been progressive and constructivist science education projects and action research programs in teacher inquiry and professional learning, e.g., OECD's Environment and Schools Initiatives.

Following the Rio Earth Summit (1992) and Agenda 21, ETE has been largely recast as a key contributor to sustainability education, particularly in preservice contexts (e.g., for early childhood, primary, secondary, tertiary, vocational, and higher education). Subsequent shifts in the focus of ETE can be identified, broadly, away from its roots in preparing teachers to engage students in collaborative, problem-solving inquiries of people-environment relations centered on curiosity and examining conflicts of interest, toward a greater emphasis on campus and community initiatives that address the UN's "mainstreaming" priorities for sustainability throughout education and advance work on the Millennium Development Goals.

Local to international discourses now articulate a wide variety of "ends-in-view" for ETE; commonalities typically include advocating teachers support the greening of institutional policies and practices, facilitate interdisciplinarity and holistic learning, model authentic school and curricular change, and further the democratization of educational goals and partnerships.

Development of Environmental Teacher Education

From its inception, ETE has been advanced to ensure that curriculum, teacher preparation, and professional development address themes of ecological integrity, economic and social justice, sustainable livelihoods, and resilient socio-ecological systems. However, relationships between ETE, science education, and EE remain varied and contested (see, e.g., scholarship from Noel Gough, Martin Ashley, and Irida Tsevreni).

Early contributions to ETE development in science education sought to ensure it was "the servant, not master" in a core of EE (see Peter Fensham), while in response to the claim that education must deliver social change – i.e., education as "*the* solution of the world's ills" – Arthur Lucas voiced pedagogical and philosophical reservations that it would become society's (and politicians') "compensatory mechanism." Lucas also warned science educators against "disciplinary chauvinism," i.e., science education regarded as *the* sole vehicle for EE.

Such concerns have resurfaced in various guises since the 1980s, most notably in debates about the priority and status of discipline-based knowledge in schools and teacher education (e.g., EE largely via geography, biology, and/or civics) and the value and shortcomings of positioning EE as an interdisciplinary and cross-curricular theme. For ETE, key questions concern the adequacy and development of teacher views regarding models for addressing environmental issues within science education and the curricular base for EE and implications for the scope and substance of professional preparation, development, capacity, and priorities. Notable tensions are the value of pursuing "whole school approaches" to EE or broader interpretations and expectations of EE providing an "education outside the classroom."

Important challenges for ETE then emerge around the interplay and tensions between the formal and informal (if not hidden and null) curriculum, as well as slippage and divergence between what is planned, enacted, and received as curriculum (see Elliot Eisner). Compounding this, mounting pressures on the professional and personal lives of teachers have been identified by Paul Hart (among others), in research that highlights the impact of the "structures and effects" of teacher values, beliefs, and experiences on EE and ETE. (Of particular note is teacher narrative research on professional preparation and development identifying "how conservative moral principles guide their behavior as responsible professionals who care deeply about children and their future.")

William Scott has argued that such considerations must equally address the layers and shifts in government policies and support for EE via ETE, while debate continues to ebb and flow as to the value of incorporating ecofeminist, critical realist, and poststructural perspectives in science education, including during ETE (e.g., see contributions from David Kronlid, Heila Lotz-Sisitka, Annette Gough). Here, key questions include how "ecocentric" the principles, processes, and outcomes of any curriculum design can actually be, as well as the benefits and risks of focusing primarily on the pragmatics (including professional standards) associated with ETE, at the expense of philosophical and pedagogical questions and challenges.

Finally, recent scholarship on the public understanding of science and science communication has reopened questions of what constitutes core subject matter, pedagogical content knowledge, and the value of science-based perspectives in curriculum planning and teacher education more broadly. For ETE, this has folded back largely into questions about focus and contribution, for example, on the centrality of inquiries about the "intrinsic value" of nature, "deficiencies" of various "root metaphors" at work in teaching and learning (e.g., education as initiation, socialization, Bildung, world-making, etc.), and appreciating the demands and shortcomings of various "ecological literacy" constructs promoted in or as EE, e.g., related to teaching and learning about climate change, ecosystem services, and biodiversity (see work by David Orr, Chet Bowers, Nicole Ardoin).

An undercurrent in many of these debates is whether ETE is, and can remain, a "hopeful educative practice." This is because while ETE is often imagined to be a vehicle for broadening, enriching, and/or redirecting (science) education via attention to environmental matters, there are few guarantees that EE achieves these qualities in or outwith the classroom. At one level, few dispute the worth of developing teachers' and students' competencies in identifying, understanding, and addressing the impacts of environmental pollution and/or the social inequalities associated with both dominant and alternative socioeconomic development trajectories. Yet research and scholarship identify a significant risk in EE becoming largely associated with practices and thinking that is tinged, if not marked, by a sense of despair or hopelessness. Moreover, "pedagogies of shock and terror" about environmental issues don't square with broader principles of effective educational practice, including productively addressing students' lifeworlds or presuming their readiness and willingness to support the pedagogue's agenda. At issue here are the cases documented in journals such as *Environmental Education Research* and *Journal of Environmental Education*, of students being confronted with apocalyptic scenarios about the future or human-environment relations, typically contained within short bursts or programs of EE that then seem to demand an immediate response and concomitant "overhaul" of lifestyle (e.g., in a lesson, or series, on ecological footprinting). Allied concerns about the strategies and tactics of "poor/bad" educational practice pinpoint the risks of programmatic approaches to EE with crude behavior change foci, marginalization of critical thinking about topics and pedagogy, and "greenwashing" of curricula and campus. Importantly, addressing these concerns in ETE might serve to guard against partisan environmentalist agendas as much as problematic teaching and the co-option of the work and lives of teachers and learners into "uneducational" activities (e.g., as discussed in the work of Bob Jickling, Arjen Wals, Chris Gayford). Equally, questions might also be raised about the spaces and times to address the ways in which education (re)creates the status quo – the charge being that teachers are often heavily constrained by vested interests about curriculum, education, and environment to the extent that the realities of human-environment relations and problems are effectively marginalized as “material” for teachers and students to work with.

The Challenge

In sum, a key issue for the future is: how far should ETE go with the various grains of education, science education, and teacher education, or might we expect ETE to always represent a radical break from any “norms” in these areas?

Cross-References

- ▶ Curriculum in Teacher Education
- ▶ Curriculum Movements in Science Education
- ▶ Inquiry, as a Curriculum Strand
- ▶ Secondary Science Teacher Education

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Epistemic Goals

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Keywords

Epistemic cognition; Epistemological belief; Metacognition; NOS (nature of science); Personal epistemology; Scientific reasoning

One of the major findings from cognitive research during the second half of the twentieth century is that how we reason is strongly influenced by the goals we pursue. Scientific reasoning, broadly speaking, is concerned with establishing causal or predictive explanations of the world and is therefore centrally concerned with what could be described as the coordination of claims and evidence. In science education, this coordination has been viewed primarily either in cognitive terms, as the acquisition and development of knowledge about the world and cognitive processes for claim-evidence coordination, or in sociocultural terms, as the appropriation of communal practices of producing and evaluating claims and evidence. (The term “claim” is used here in a very broad sense to subsume theories, which are typically networks of claims articulated to relate in ways that explain target phenomena, and more specific or granular claims of the sort, “x causes y.”) Within both perspectives, goals are theorized to orient and constrain reasoning. Epistemic goals are those related to efforts to know something.

Epistemic Goals and Scientific Reasoning

Understanding children’s and adults’ competencies at scientific reasoning has been a longstanding concern of psychological research, going back at least to the work of Piaget and colleagues in the middle of the twentieth century examining the logical thinking of children and related work on logical reasoning and hypothesis testing in adults. Piaget’s studies suggested that children did not develop the capacity to think logically, in terms of abstract relations and causal consequences, until adolescence, and related work suggested adults routinely failed to test hypotheses systematically and are biased to confirm hypotheses. A famous example is Wason’s four-card problem, in which subjects are shown a sequence of cards, such as “4,” “A,” “7,” and “D,” and asked which card(s) need to be turned over to disconfirm a rule: “if a card has a vowel on one side, then it has an even number on the other." Most people choose the cards ("A" and "4") that confirm the rule rather than disconfirm it, and this is cited as evidence that most people are unscientific. Recasting such problems in more familiar terms, like "If a letter is sealed, then it has a 20 cent stamp on it," drastically improves performance. Moreover, it appears that performance on these sorts of tasks is not tied simply to prior experience but whether or not the rule at stake has a comprehensible rationale.

Similarly, there is a fair amount of evidence that children, and even adults, often fail to interpret covariation evidence as suggestive of causal relationships. Particularly, Deanna Kuhn has shown a variety of ways in which people seem to fail in coordinating such evidence with claims. One explanation of these findings is that people seek plausible causal mechanisms to explain covariation data and discount the causal import of covariation when a plausible mechanism cannot be generated (Kuhn, 2001). From such tasks and the hypothesis testing work discussed above, we can conclude that people's reasoning is guided by epistemic goals for plausible mechanisms and comprehensible reasons for rules.

Another example from cognitive psychology demonstrates the link between the goals we pursue while reasoning about complex tasks and how we reason. Kevin Dunbar created a computer microworld where college students simulated experiments to discover how gene inhibition works. During a learning phase, subjects learned core concepts to help them use the microworld and biased them toward a wrong hypothesis of gene inhibition. Subjects' success at finding the correct rule varied depending upon whether or not they pursued a goal of finding evidence for their current hypothesis versus a goal of finding a hypothesis that could explain their data. Subjects who pursued a "find hypothesis" goal were much more systematic in their experimentation strategies with the microworld.

These examples illustrate a robust finding from cognitive research into children's and adult's scientific reasoning: the goals one pursues during a complex reasoning task influence how that reasoning occurs. To be sure, it is also the case that a person's prior knowledge about the area of investigation (e.g., how much one knows about genetics or electric circuits) also influences reasoning (Lehrer & Schauble, 2006; NRC, 2007). The influence of goals, over and above prior knowledge, is in how it orients people to such problem-solving activity.

Epistemic Cognition and Goals

Epistemic goals are one aspect of epistemic cognition, a construct introduced by Karen Kitchener in 1983 to account for the kinds of thinking required to solve ill-structured problems. Ill-structured problems are those that have no single correct answer or any single path to a reasonable answer. Science is obviously full of ill-structured problems, and the myriad socioscientific issues (climate change, disease risk, etc.) people encounter are also ill-structured. For Kitchener, epistemic cognition is a specification of the more general process of metacognition. Metacognition involves monitoring one's progress toward solution of a problem and selecting appropriate problem-solving strategies. Epistemic cognition involves reasoning about the nature of an appropriate solution – what counts as an answer – and the criteria of a "good" answer to a problem from the perspective of a given domain or discipline. It is not simply a matter of being metacognitive and asking, "am I making progress?" It also entails some idea of what progress looks like and how it is evaluated (Kitchener, 1983). To design a successful science experiment, for example, requires some understanding of what counts as a good experiment, what experiments are intended to achieve, and so on.

The answers to such epistemic questions are effectively epistemic goals and strategies for achieving them, such as control of variables as a strategy for meeting the goal of isolating causal relationships. This emphasizes the disciplinary specificity of epistemic cognition and highlights that expertise in a discipline, be it science or history or math, entails not simply an understanding of the core concepts of that discipline but also an understanding of its epistemology. The broad epistemic goal of science to construct causal accounts of the natural world leads to an array of epistemic strategies, empirical methods, and inferential strategies for satisfying that goal. Consequently, science learning is now seen to require learning the epistemic practices and standards of science in addition to science concepts. In fact, we can go so far as to say that current views on science education emphasize how science concepts emerge from particular practices of knowledge development, a rejection of the traditional content/process dichotomy (Duschl, 2008; Ford & Forman, 2006).

Epistemic Cognition and Nature of Science

Epistemological concerns in science education have historically been studied under the rubric of nature of science (NOS). NOS research has been concerned with documenting the extent to which students understand the current philosophical characterization of the nature of science. This nature of science is commonly characterized in terms of the nature of scientific knowledge, means for justifying scientific knowledge, and social aspects of science as a human enterprise. NOS research extends back to the late 1950s, a period of time that has seen a great deal of change in philosophical characterizations of science that remain contested to this day. NOS research is treated elsewhere in this volume but bears on epistemic goals in two ways. First, there is some evidence suggesting that learners' views of NOS are associated with how they try to learn science. Learners who see scientific knowledge as interconnected concepts and as historically dynamic appear to pursue deeper learning strategies than those who see science as a collection of static, unconnected facts or ideas. This supports the general finding already discussed that epistemic goals influence reasoning. At the same time, the survey and interview instruments used to assess NOS often fail to characterize clear epistemological perspectives in students, and there is now considerable evidence that students reason about epistemological issues differently in contexts that are familiar to them than when abstract questions are posed to them about science.

The second point to make here is that NOS research has not concerned itself very directly with epistemic cognition. Conversely, the voluminous research on students' experimentation and investigation – ill-structured scientific problem solving – is largely disconnected from NOS research. On the one hand, NOS research does not treat learners' own epistemic goals as an object of study, but asks only whether or not students understand the epistemic goals of science. On the other hand, work on scientific reasoning, including that on students' scientific inquiry, focuses nearly exclusively on how individuals (or small groups) set and pursue epistemic goals without connecting such personal knowledge construction to students' notions of the epistemic goals and practices of professional science. This has meant that the relations between students' own epistemic cognition and their conceptions of the nature of science remain poorly understood (Sandoval, 2005).

Personal Epistemologies

Epistemic goals can be seen as being derived from individuals' beliefs about the nature of knowledge and knowing. The study of such beliefs is known as "personal epistemology" research (Hofer & Bendixen, 2012) and historically has been conducted largely independently of research in science education (or other subjects). Personal epistemology researchers generally argue for a developmental progression across the lifespan from an absolutist stance in early to middle childhood that sees knowledge as simple, knowable with certainty, and justified by trusted authorities, through an unmoored multiplism (or relativism) where knowledge is uncertain, authoritative sources are untrustworthy, and all knowledge claims are equally justifiable. This multiplism is resolved into an evaluative stance that views knowledge as constructed, not knowable with absolute certainty, but asserts that knowledge claims can be justified according to standards of reason and evidence. There are various lines of evidence to support the possibility of such a progression, but a range of findings, many from science education, violate predictions from current personal epistemology models.

Personal epistemology research shares with NOS research the assumption that people develop stable beliefs about knowledge and knowing that directly relate to the epistemic goals and strategies they might pursue. In the last two decades, the evidence for such stability has been sharply questioned in light of findings that the epistemic cognition people engage in appears to vary according to the context of reasoning.

Cultural Perspectives on Goals and Learning

To this point, epistemic goals have been framed solely in individualistic terms: a person's goals for constructing or evaluating knowledge claims influence their processes of construction and evaluation. Yet, in the same way that science studies have shown science to be a culturally and historically situated enterprise, the emergence of sociocultural perspectives on cognitive development and learning frame cognition as socially, culturally, and historically situated. A situated perspective on cognition directs attention away from individual mental processes and toward processes of social interaction, including the ways goals get formulated, interpreted, and pursued. This shift has implications for how epistemic cognition is theorized and how research on epistemic goals and cognition gets carried out.

From a sociocultural perspective on cognition, all knowing is situated in activity. This implies that an individual's epistemic goals within any particular situation emerge in interaction with perceived features of the situation itself and other people involved. Thus, as those features or people change, epistemic goals can change. Furthermore, from this perspective epistemic goals can be considered themselves to be collective and not just individual – individuals' participation in activity is interpreted in relation to their alignment with current goals. From this point of view, then, the forms of epistemic cognition an individual may engage are tied to these interactional, inherently social contexts and thus are not assumed to be stable features of an individual's cognitive structure. One consequence of this perspective is that people's performances on research tasks to assess things like scientific thinking or epistemic belief are themselves seen as particular social contexts instead of neutral means of eliciting stable conceptions or beliefs.

Consider the four-card problem described earlier. A sociocultural (or situated) perspective on that task would interpret "failure" on that task as a misalignment between subjects' goals in the task (e.g., to get course credit for one's participation) and researchers' goals, rather than as a stable indication of a lack of skill. Their improved performance in the contextually grounded versions of the task would be interpreted as such contexts being culturally meaningful, thus triggering epistemic goals relevant to the task.

An example within science education is research on scientific argumentation. It is a common finding that students often fail to justify how particular pieces of data provide evidence for specific claims. A cognitive explanation is that these students lack the skill to justify, whereas a sociocultural explanation is that students do not recognize that justification is necessary (and may not have knowledge of communal, i.e., scientific, standards of justification). The sociocultural perspective treats epistemic goals as socially, rather than individually, generated and therefore tends not to assume that participants in interaction share the same epistemic goals.

This means two things for epistemic goals and their influence on cognition and science learning. One is that learning science necessarily entails learning about the epistemic goals that scientists pursue and how what we casually call "scientific method" has developed in various ways to achieve those goals. This has several implications for science teaching, the most basic being that the epistemic goals of science, as a human enterprise, should become a core part of instruction. Learning the practices of science necessarily entails learning how those practices support specific epistemic goals.

The second implication from the sociocultural perspective is that research on epistemic cognition, including epistemic goals, requires attention to the contexts that individual students may find themselves reasoning in and with whom they are participating. This includes an attention to processes of interaction in ways that can illuminate how epistemic goals are nominated and taken up. It also includes acknowledgment from researchers that the means of eliciting or observing students' epistemic goals are themselves particular kinds of social interactions. Filling out a survey about the nature of science or participating in an interview about one's own inquiry project is assumed, within this perspective, to trigger different goals in participants and thus different forms of cognition. Therefore, cognition cannot be understood independently of the goals pursued by participants.

Current Questions and Issues

To summarize, there is extensive and robust evidence that individual's epistemic goals influence reasoning and learning. Epistemic goals are generated in relation to particular situations of reasoning or problem solving, and there is abundant evidence from both cognitive and sociocultural perspectives on cognition that shifting people's goals within a task shifts their reasoning. The relation between epistemic cognition, including epistemic goals, and the conceptions people have about knowledge and knowing, including scientific knowledge and the nature of science, remains unclear. There has been much research on students' reasoning during investigation, experimentation, and argumentation tasks and also much research on students' conceptions of nature of science. There is as yet relatively little research connecting these two, and epistemic goals may be the connection between the two, to the extent that conceptions of the nature of science may generate epistemic goals that reasoning practices are meant to meet.

Cognitive and sociocultural perspectives on cognition take very different views on these relations, however. Cognitive views posit knowledge and belief as mental structures that generate goals that direct the application of cognitive strategies and that these various mental structures are open to inspection. Sociocultural views theorize knowing as inextricably situated in activity and consequently tend to view observations of practice as the only meaningful indicator of what people know, discounting efforts to elicit espoused beliefs. Hybrid approaches accept the situated nature of cognition while asserting that localized cognitive structures guide reasoning. This somewhat simplistic distinction between what are, in fact, a great variety of specific theories across two broad schools of thought is intended simply to emphasize that the general perspective on cognition and development one takes has a strong influence on how epistemic goals, and epistemic cognition more generally, are conceptualized and studied.

Regardless of the perspective researchers take, several issues related to epistemic goals and their development remain open in science education. One, already mentioned, is the need to develop a better understanding of how learners' epistemic goals during their own efforts to learn science may relate to and be used to develop understanding of the nature of science. Another is how instruction can promote epistemic goals that enhance students' science learning. A third issue is understanding the epistemic goals people pursue in science-related activities outside of school, their strategies for pursuing them, and how such epistemic cognition relates to learning science in school. Epistemic goals have emerged as an important focus of science education research, and there are many avenues of research to clarify their relation to learning science and using science productively in everyday life.

Cross-References

- ▶ Agency and Knowledge
- ▶ Companion Meanings
- ▶ Epistemology

- ▶ Inquiry, Learning Through
- ▶ Metacognition and Science Learning
- ▶ Nature of Science, Assessing of

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Epistemology

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Cognition, social, and institutional processes; Inquiry; NOS (nature of science); Scientific methods

Epistemology is the branch of philosophy that addresses questions involving our ideal cognitive aims and achievements, which include knowledge, justification, explanation, understanding, and wisdom. Epistemology is distinct from the two other branches of philosophy, i.e., metaphysics (which deals with questions of existence, reality, and ontology) and ethics (which deals with questions of moral value and right action). The kinds of questions considered by epistemologists include the following: What are knowledge, justification, explanation, understanding, and wisdom? Can these epistemic aims be attained? If so, how might these epistemic aims be attained? These questions thus concern our cognitive relations and access to the world and so explore the various sources of human knowledge, including perception, memory, reason, testimony, intuition, introspection, revelation, and scientific inquiry. Epistemology also addresses the legitimacy of our claims to know or be justified and so addresses questions of truth and skepticism as part of the effort to develop a coherent theory that specifies the nature, range, and limits of our knowledge.

The scope of the philosophical field of epistemology is very broad. While some philosophers (e.g., Plato) have attempted to develop a philosophical analysis (or definition) of key epistemic concepts by specifying their necessary and sufficient conditions, others (e.g., Rene Descartes) have investigated whether we do, in fact, know what we claim to know and how we are justified in taking what we believe to be knowledge. Still other philosophers (e.g., Aristotle) have focused on delimiting the epistemic virtues, vices, and values which serve to help or hinder the attainment of our cognitive goals of knowledge, wisdom, and understanding. Contemporary epistemologists (e.g., Alvin Goldman) have further focused on the causal, cognitive, social, and institutional processes that underlie knowledge production, including the distinctive methods of scientific and other kinds of inquiry. Contemporary epistemology has thus focused increasingly on both the natural and social dynamics implicated in the construction of knowledge. Naturalist epistemologists (e.g., Philip Kitcher) have thus worked to specify the reliable processes upon which knowledge production depends (including perceptual and testimonial processes), and feminist epistemologists (e.g., Lorainne Code) have explored the ways in which social values and power relations affect the creation and dissemination of knowledge (Moser 2002b).

Many of the core concepts that feature in philosophical epistemology have found a home in the work of psychologists and science educators. However, these researchers have adopted epistemological concepts in order to understand and improve actual human cognition, rather than to advance philosophical inquiry. Research psychologists working in this field have investigated human cognitions relating to knowledge and knowing, including both tacit and explicit beliefs about what knowledge is, how knowledge is obtained, and what kinds and sources of knowledge exist, as well as how that knowledge is justified by both novices and experts across a range of topics and domains. Although the target of this research has been characterized variously as epistemological beliefs, epistemic beliefs, personal epistemology, epistemological reflection, and reflective judgment, the term epistemic cognition has been widely adopted as a unifying description.

There are roughly two (somewhat overlapping) strands of psychological research in which epistemic concepts feature prominently: the developmental and the doxastic traditions. The developmental approach, exemplified in the work of William G. Perry, investigates the epistemic trajectories that characterize cognitive development, from naïve to sophisticated epistemic subjects. Researchers working in this tradition seek to understand cognitive development in terms of a progression through a predictable sequence of successive epistemic stages of increasing sophistication, from epistemic novices who adopt absolutist, dualist, or relativist epistemologies through to epistemic experts who reflectively weigh multiple perspectives (Perry 1999). The alternative doxastic approach, exemplified in the work of educational psychologists like Barbara K. Hofer and Paul R. Pintrich, focuses on a multidimensional set of relatively independent beliefs which characterize the cognition of the epistemic subject, including dimensions of the certainty, simplicity, justification, and sources of knowledge. The doxastic tradition typically uses questionnaires and factor analysis to find correlations between academic variables and scores on measures developed from these multidimensional models of epistemic cognition and to use these correlations in designing effective instruction (Hofer and Pintrich 1997). These two distinct stands of research have grown into a rich and prolific body of research that investigates human psychology using conceptual tools originally developed by epistemologists, with the goal of using psychological models of epistemic cognition to explain and predict variation in the processes and outcomes of learning and reasoning.

In light of the profusion of work in contemporary epistemology, Chinn et al. (2011) have proposed an expanded conception of the dimensions of epistemic cognition, with the goal of developing more sophisticated, fine-grained, and comprehensive psychological models. The expanded conception includes (a) epistemic aims and values (including the interaction between epistemic and non-epistemic aims), (b) the structure of epistemic achievements including knowledge and understanding, (c) the sources and justification of epistemic achievements, as well as epistemic stances including certainty and plausibility, (d) epistemic virtues and vices, and (e) reliable and unreliable processes for achieving epistemic aims. The revised framework includes both individualistic and social features of knowledge production within each component, in order to capture a richer and more fine-grained profile of the full range of epistemic commitments and dispositions of research participants. The framework also emphasizes a dual focus on epistemic cognition, both in terms of the potentially tacit epistemological commitments that people manifest through their behavior (e.g., the degree to which they demonstrate the epistemic virtue of open-mindedness) and in terms of the explicit beliefs they have about a range of epistemic concepts (e.g., their reflective beliefs about the role and value of open-mindedness in inquiry) (Chinn et al. 2011).

Work in philosophical epistemology has particular relevance for science education and research.

This is because an important goal of many science educators (e.g., Norman G. Lederman) is for science learners to develop an understanding of the nature of science, an understanding which is underpinned by an awareness of how scientific methods and processes serve to generate as well as justify scientific knowledge. These science education researchers thus investigate peoples' scientific epistemology, which involves their beliefs about how scientists, scientific processes, and scientific practices are implicated in the production of scientific knowledge.

Disagreements among science education researchers in terms of the epistemological basis of science have influenced the ways in which science education has been pursued. For example, Richard Duschl has critiqued those conceptions of science embodied in science instruction which present scientific knowledge as if it were a completed product, rather than as a tentative set of models and practices that are continually subject to critique and revision. This critique is part of a wider call for a more "epistemologically authentic" science education, in which learners engage in the reasoning and evidential practices of genuine scientists, rather than solely in the memorization of what is considered to be an accepted body of scientific facts. Differences in epistemological beliefs about the nature of science can therefore have a considerable impact on science education policy and practice.

Researchers in science education have also disagreed about the nature and structure of the epistemological knowledge that successful science learners should be able to manifest, as well as the methodology that is best suited for tracing science learners' epistemic commitments with regard to science. For some researchers, science learners' scientific epistemologies consist of relatively stable, coherent systems of explicit and general beliefs about scientific methods and knowledge. These researchers thus tend to rely on questionnaire assessments to trace learners' scientific epistemologies. For other researchers (e.g., David Hammer), the epistemic cognition of science learners tends to be fragmentary, inconsistent, and unstable, which entails that the beliefs articulated in response to questionnaire assessments might not provide much insight into the real underpinnings of a participant's actual epistemic cognition about science. Another locus of disagreement among science education researchers that is epistemologically relevant concerns how a learner's scientific epistemology is manifested in their behavior. For some researchers, like William Sandoval, a person's true epistemic commitments are revealed through their actual inquiry practices, rather than through the traditional pencil-and-paper mass assessments which tend to trace only those epistemic commitments which are subject to conscious reflection and articulation. This is demonstrated by learners (and even scientists) who demonstrate poor insight into the epistemological foundations of good scientific practice, yet who nonetheless engage in sophisticated and productive scientific inquiry. This distinction is thus between a subject's "formal epistemology" of science, involving their explicit beliefs about science and scientific practice, and their "practical epistemology" of science, which involves the often tacit commitments and dispositions that guide their actual inquiry practice. These theoretical and methodological disagreements are thus founded on different conceptions of the role and structure of the epistemic commitments that underlie good scientific reasoning, and resolving them will require grappling with their epistemological foundations.

The philosophical field of epistemology therefore represents an important resource for purposes of science education and research. Epistemologists have uncovered a host of interconnected concepts and issues which are of vital importance in bringing science learners to a sophisticated understanding of the nature of scientific knowledge and practice. In addition, resolving some of the key conceptual and methodological disagreements that characterize the field of science education research requires unpacking the epistemological fault lines that underlie these disagreements.

Cross-References

- ▶ Agency and Knowledge
- ▶ Epistemology
- ▶ Feminism and Science Education
- ▶ Inquiry, Learning Through
- ▶ Metacognition and Science Learning
- ▶ NOS: Cultural Perspectives
- ▶ NOS, Measurement of

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Equilibration and Disequilibration

▶ Piagetian Theory

Ethnoscience

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Ethnoscience is a one-word conundrum, since its two parts – “ethno” and “science” – are in tension, if not outright opposition. Science is culture-free by definition: science claims to be universal knowledge, which applies equally everywhere. The prefix “ethno” has the meaning of “cultural,” so the word “ethnoscience” literally means “cultural science.” This notion of “cultural science” flouts the criteria of science and is denied by most working scientists.

Ethnoscience is a more technical form of two-word terms such as Indigenous knowledge, Native science, and many versions such as “African science,” “Maori science,” etc. This notion has been influential in education, where programs of reform in a number of countries have been based on incorporating Indigenous knowledge into the school science curriculum (Aikenhead and Michell 2011).

The concept of ethnoscience has two complementary parts: one, recognition of the basis in science of relevant parts of traditional cultural narratives and practices; the other, respect for traditional indigenous philosophies and worldviews, which explained the world in the absence of modern science tools and concepts.

The problem with the word ethnoscience (and its cognates including ethnobiology, ethnochemistry, and ethnophysics) is that its technical form obscures the political issues and philosophical debates inherent within this complex concept. Ethnoscience is of little value to indigenous people when it is understood as an alternative form of science on which culturally relevant science education can or should be based. The concept of ethnoscience reminds science of its basis in culture: as a human form of knowledge, science can aspire to, but never fully attain, the criteria for knowledge that are regarded as its essential characteristics, such as objectivity and universality. This humbling of science is the actual value for science of the vexatious concept of ethnoscience (Boyd 2001).

One example of this use of the concept of ethnoscience is the debate in Aotearoa New Zealand over “Māori science,” which led a local European New Zealand scientist to call into question the coherence of the term “Western science” (Dickison 1994). “Māori science” was concluded by Māori science educators to be, in essence, a protest against the conflation of the term “Western science” with “science” (McKinley 2001). The inbuilt Eurocentrism and elitism in the secondary school science curriculum alienate almost all Māori students, making it the most effective social gatekeeper for the professions. This is not to deny the importance of the ethnic literacy and numeracy gap in explaining the massive underrepresentation of indigenous students among those who successfully study science through to the end of school and beyond. But there is also a scientism rampant within school science, which, over and above the Eurocentric, sexist, and elitist distortions or “myths” of the school science curriculum (Hodson 1999), has “attached itself parasitically to science over the last two hundred and fifty years” (Charlesworth 1982, p. 46). Two aspects of this scientism are, firstly, the amnesia by which school science programs celebrate science’s successes but omit its failures (Benson 1989) and secondly the confusion of the aspiration to objectivity with its attainment (Aikenhead 2008).

Cross-Reference

- ▶ Indigenous Knowledge
- ▶ Indigenous Knowledge Systems and the Nature of Science
- ▶ Science Curricula and Indigenous Knowledge

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Evaluation

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The etymology of the term evaluation is quite clear, and the Old French core provides the foundation of its definition. With “value” at the core, an evaluation is the systematic process by which the value of something is ascertained. Typically, in science education, evaluation focuses on a judgment of the value, merit or worth of a person, product, plan, proposal, program, or policy. Fournier (2005) defines evaluation as an investigation that combines the collection of evidence with synthesis relative to some standard or normative judgment to result in a determination about the condition of an entity. The value element is what makes evaluation differ from assessment and what forms the theoretical grounding by which the evaluation is structured. Evaluations range from an objective, goals-focused process to an examination of the lived experiences of the participants in the context being evaluated. The Joint Committee on Standards for Educational Evaluation has developed a set of standards for student, educational personnel, and program evaluation that describe the attributes of quality evaluation in education (Gullickson 2004, 2008; Yarborough et al. 2010).

An issue of New Directions for Evaluation identified a number of key issues for evaluation in science, technology, engineering, and mathematics (STEM) education (Huffman and Lawrenz 2006). Perhaps the most controversial issue in STEM education evaluation is the premise that evaluation designs that randomly assign participants to a treatment and control group, as the “gold standard” of evaluation, use the only methodology that can determine causality in educational settings, with quasi-experimental studies a distant second. Alternatives include multi- or mixed methodological approaches to evaluation that incorporate randomized designs as an integral part of more comprehensive and methodologically diverse evaluations (Raudenbush 2005). Lawrenz and Huffman (2006) present an evaluation framework for STEM education that includes multiple quantitative and qualitative evaluation designs to examine the efforts of a project or program. These designs range from descriptions and surveys to interpretive designs based on a particular conceptual or theoretical stance, to case studies, to more correlational, quasi-experimental, and experimental designs. Evaluation designs that incorporate multiple methodologies afford the examination of a project or program from multiple dimensions.

STEM evaluation is also concerned with the issue of determining the outcomes of projects and programs on diverse audiences and cultures (Mertens and Hopson 2006; Greene et al. 2006). Evaluation designs might incorporate a perspective of social justice or cultural diversity as the lens by which to examine the value of a project, program, or policy. As new data sources for evaluation, such as local and state data systems, continue to evolve, evaluation capacity becomes an even more important issue (Huffman et al. 2006; Penuel and Means 2010).

Cross-References

- ▶ Assessment: An Overview
- ▶ Program Evaluation

References

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Evaluation of Textbooks: Approaches and Consequences

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Research in science education has recognized the importance of textbooks for learning science effectively. In many parts of the world, for most science teachers at the secondary, high school, and introductory university level courses, the textbook is the only source of information and guide to classroom practice. Given this widespread use of textbooks in most educational systems, their evaluation for improvement is an integral part of the research agenda.

It is important to differentiate two types of approaches related to the evaluation of science textbooks that can be classified as:

(a) Domain-general: These studies are based on a series of criteria that can be used for evaluating whole textbooks across disciplines (biology, biochemistry, chemistry, earth science, physics, other). Some of the criteria are related to nature of science, scientific literacy, inquiry, analogies, photographs, gender, comprehensibility, readability, vocabulary load, graphical information, and cultural and religious sensibility.

(b) Domain-specific: These studies are based on a historical reconstruction of a given topic of the science curriculum, and the criteria developed can only be used for that particular topic.

Domain-General Studies

Chiappetta et al. (1991) analyzed seven US high school chemistry textbooks to evaluate the following aspects of scientific literacy: (a) science as a body of knowledge; (b) science as a way of investigating; (c) science as a way of thinking; and (d) interaction among science, technology, and society. Authors found that all of the chemistry textbooks analyzed de-emphasize science as a way of thinking and do not stress the importance of how chemists discover ideas and experiment, the historical development of chemistry concepts, cause-and-effect relationships, evidence and proof, and self-examination of scientist's thinking in the pursuit of knowledge. These aspects of the scientific enterprise constitute an important part of scientific literacy.

Nature of science (NOS) as presented in five Turkish secondary school biology textbooks was evaluated by Irez (2009). Based on the literature, the following 11 themes regarding NOS were identified: description of science, characteristics of scientists, scientific method, empirical basis of NOS, tentative basis of NOS, nature of scientific theories and laws, inference and theoretical entities in science, subjective and theory-laden NOS, social and cultural embeddedness of science, imagination, and creativity in science. Based on these themes, the author also generated cognitive maps regarding NOS that provided an overall picture of how science is depicted in each textbook. Results obtained revealed that discussions regarding NOS represented a very small part of the textbooks, and science was generally portrayed as a collection of facts and not as a dynamic process of generating and testing alternative explanations about nature. Of the 11 NOS themes studied, the author considered the following to be particularly misrepresented: scientific method and the tentative nature of scientific knowledge.

Textbook analogies have the potential to become an important learning resource, as some students require alternative presentations of concepts to learn meaningfully and also serve to make the text more user-friendly. Orgill and Bodner (2006) have analyzed the use of analogies in eight US introductory university level biochemistry textbooks. In order to evaluate the textbooks, analogies were classified in the following areas: (1) content of the target concept, (2) location of the analogy in the textbook, (3) analogical relationship between analog and target, (4) presentation format (verbal or pictorial), (5) level of abstraction of the analog and target concepts, (6) position of the analog relative to the target, (7) level of enrichment (How much mapping is explicit? Is the analogy simple, enriched, or extended?), (8) analog explanation (in order to be useful, some degree of explanation is necessary), (9) indication of cognitive strategy, and (10) limitations of the analogy. Results obtained revealed that the use of analogies in biochemistry textbooks is quite similar to that of secondary textbooks in different subject areas. A major finding of the study is that none of the analogies used are completely explained, very few are identified as "analogies," and the limitations of the analogies are rarely mentioned. Of the 158 analogies found in these textbooks, only seven "limitations of analogies" were found, and 23 included a pictorial representation. It is suggested that textbook authors need to improve such aspects in order to make the role of analogies more explicit.

Stern and Roseman (2004) have analyzed nine middle school (grades 6–8, ages 12–14) curriculum materials (textbooks and teacher guides) that are widely used in the USA. These materials were analyzed by educators and scientists trained in the use of the Project 2061 curriculum analysis procedure, based on seven criteria that sought to give a comprehensive and wide in scope approach. The seven criteria are *I: Identifying and maintaining a sense of purpose*; *II: Taking account of student ideas*; *III: Engaging students with relevant phenomena; IV: Developing and using scientific ideas*; *V: Promoting student thinking about phenomena, experiences, and knowledge*; *VI: Assessing progress*; and *VII: Enhancing the science learning environment*. (See the entry *Textbooks: Impact on Curriculum* for detail of the categories.) The following topics in these materials were analyzed: kinetic molecular theory (physical science), flow of matter and energy in ecosystems (life science), and processes that shape the Earth (earth science). Materials were evaluated on the following scale: 0–1.0 = poor, 1.5 = fair, 2 = satisfactory, 2.5 = very good, and 3 = excellent. For the life science topic, on Categories I–VI (Instructional criterion), none of the textbooks were classified as excellent on any category; two textbooks were classified as very good, one on Category I and the other on Category IV; and two textbooks were classified as satisfactory (one on Category I and the other on Categories I and II). In addition to these quantitative results, the authors also provide various examples of how the treatment of photosynthesis and respiration often focuses on naming reactants and products rather than on the idea that matter and energy are being transformed into other substances or other forms of energy. Finally, the authors concluded that currently available materials are not likely to contribute to the attainment of benchmarks related to matter and energy transformations in living systems.

Domain-Specific Studies

When Thomas Kuhn directed the Project “Sources for History of Quantum Physics,” he raised a provocative question: Who first proposed the quantum hypothesis? And he concluded that it was A. Einstein who first recognized that the black body law could not be derived without restricting resonator energy to integral multiples of hν (h = Planck’s constant; ν = frequency). This historical reconstruction shows that Einstein’s formulation of the quantum hypothesis provided greater explanatory power than that of M. Planck. In other words, Planck in 1900 simply introduced an approximate mathematical quantization in doing the calculations. In order to evaluate the inclusion of Kuhn’s thesis, Brush (2000) has analyzed 28 general physics textbooks published in the USA (1990–1997). Results obtained showed that only six textbooks included Kuhn’s hypothesis with respect to the origin of the quantum hypothesis.

Based on a historical reconstruction of the atomic models of Thomson, Rutherford, and Bohr, Niaz (1998) has analyzed 23 general chemistry textbooks published in the USA. All textbooks were evaluated on eight criteria which were validated by inter-rater agreements. Results obtained revealed that most textbooks emphasize experimental details based on observations, leading to the presentation of scientific progress as a *rhetoric of conclusions* based on irrevocable truths. Such presentations in textbooks lack the conceptualizations of *heuristic principles* that led the scientists to design and interpret their experiments. For example, one of the criteria dealt with the Thomson-Rutherford controversy with respect to the single/compound scattering of alpha particles. Both Rutherford and Thomson performed similar experiments on the scattering of alpha particles, but their interpretations were entirely different. Thomson propounded the hypothesis of *compound scattering*, according to which a large angle deflection of an alpha particle resulted from successive collisions between the alpha particles and the positive charges distributed throughout the atom. Rutherford, in contrast, propounded the hypothesis of *single scattering*, according to which a large angle deflection resulted from a single collision between the alpha particle and the massive positive charge in the nucleus. This rivalry led to a bitter dispute between the two proponents. Rutherford’s dilemma was that, on the one hand, he was entirely convinced and optimistic that his model of the atom provided a better explanation of experimental findings, and yet it seems that the prestige, authority, and even perhaps some reverence for his teacher (Thomson) made him waver in his conviction. A science student may wonder why Thomson and Rutherford did not meet over dinner (they were well known to each other) and decide in favor of one or the other model. These issues, if discussed in class and textbooks, could make the presentation of science much more human and motivating. Interestingly, none of the general chemistry textbooks (Niaz 1998) presented this historical episode.

Most general chemistry textbooks consider wave-particle duality as important for understanding atomic structure. After presenting the atomic models of Thomson, Rutherford, and Bohr, textbooks present Einstein’s photoelectric effect and then Louis de Broglie’s hypothesis of wave-particle duality. Based on a historical reconstruction, Niaz and Marcano (2012) have analyzed the presentation of wave-particle duality in 128 general chemistry textbooks (published in the USA). Criteria based on the following historical aspects were evaluated: (1) Einstein and de Broglie suggested wave-particle duality before there was any conclusive experimental evidence; (2) De Broglie suggested how matter waves could be observed experimentally; (3) Importance of Davisson-Germer experiments and their struggle to interpret experimental data; (4) Role of similar experiments by G.P. Thomson; (5) Controversial nature of wave-particle duality and de Broglie's reputation as an obstacle in the acceptance of his theory; and (6) Why was it Schrödinger who developed de Broglie's ideas? Textbooks were classified as Satisfactory (S), Mention (M), and No mention (N). Results obtained revealed that none of the textbooks described satisfactorily criteria 2, 3, 5, and 6. Some textbooks described satisfactorily the postulation of wave-particle duality before there was any conclusive experimental evidence, and very few textbooks referred to similar experiments being conducted by two groups of scientists. In general, historical details are generally ignored or distorted by most general chemistry textbooks. This study provides science teachers with various historically based presentations which provide the necessary background for improving students' understanding of wave-particle duality. It is plausible to suggest that the topic of wave-particle duality can facilitate students' classroom discussions and understanding of how science progresses.

Conclusion

Evaluation of science textbooks is an important guide for their improvement. Textbook authors are generally not aware of research related to evaluation of textbooks. Studies related to both domain-general and domain-specific aspects can provide guidelines for the constant revision of science textbooks. In order to facilitate students' understanding of how science progresses and motivation to study science, the following aspects can be included in textbooks:

(a) Inclusion of scientific literacy themes, nature of science, and analogies
(b) If there is no one way of doing science, which of the following two is more important for scientific progress: experimental evidence or theoretical insight?
(c) When scientists do experiments do they always know beforehand what they are going to find?
(d) If two groups of scientists interpret the same experimental data differently, does that mean that one of them is not being sufficiently "objective"?
(e) Is it possible for two groups of scientists to use different experimental techniques and arrive at the same results and conclusions?
(f) If two theories are proposed to understand the same phenomenon, can the scientific community help to resolve the controversy?

Cross-References

▶ Nature of Science, Assessing of
▶ Program Evaluation
▶ Scientific Literacy

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Evidence-Based Practice in Science Education

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> The special task of the social scientist in each generation is to pin down the contemporary facts. Beyond that, he shares with the humanistic scholar and the artist in the effort to gain insight into contemporary relationships, and to align the culture's view of man with present realities. (Cronbach 1975, p. 126)

Evidence-based practice in science education is the conscious, explicit, and judicious use of current best evidence to make and implement decisions. The best evidence comes from rigorous empirical research on the efficacy of interventions for improving students' science learning.

Many science education reformers look to evidence-based practice in medicine as a model. Our definition is consistent with Sackett et al.'s (1996) definition of evidence-based medical practice, and there are similarities between the fields. For example, both medicine and education face considerable organizational challenges. Organizations may not seek best practices or support continuous improvement of their processes. However, there are also important differences between medicine and education. For example, "treatment dosage" is better controlled in the former (e.g., pill, inoculation) than in the latter (e.g., curriculum, innovative practice, small class size), especially if teachers "deliver" the treatment in their own particular ways.

Three parts of our definition of evidence-based practice warrant unpacking. First, what counts as rigorous empirical research? Second, what counts in making decisions about practice? And, third, what counts in implementing these decisions? Empirical evidence alone is typically not determinative of what, in the end, is regarded as "best practice." More than empirical evidence should come into play – these include well-grounded values and beliefs; clinical or classroom norms and practices; feasibility of implementing decisions with high fidelity; time, cost, and other practical constraints; and social and cultural processes and structures. Perhaps the label suggested by Hargreaves – "evidence-*informed*" – is more apt than "evidence-*based*" decisions and practice.

Rigorous Empirical Research

Rigorous empirical education research is often translated as "scientific research" on the efficacy of alternative practices, interventions, or programs. These alternatives are typically under consideration by a decision maker (teacher, administrator, policy maker) concerned with student learning (including cognitive, intrapersonal, and interpersonal achievements).

While "scientific research" belies definition, it has a number of defining characteristics that, taken together, circumscribe it (Shavelson and Towne 2002). Scientific research poses questions that can be empirically tested, links these questions to what is already known, uses methods that permit direct investigation of these questions, provides a coherent and explicit chain of reasoning for resulting inferences, is replicable, generalizes across studies, and passes the test of professional scrutiny and critique. In the context of evidence-based practice, such research puts alternative interventions to the empirical test by bringing data to bear, ruling out counterhypotheses as to what works and why, and logically justifying conclusions with data.

Scientific research is not and should not be equated with randomized experiments; research designs should follow from the empirical questions posed. Sackett et al. (1996) made a similar point: "Evidence-based medicine is not restricted to randomized trials and meta-analysis it involves tracking down the best external evidence with which to answer our clinical questions" (p. 72).

Three generic questions might be posed in evaluating alternative practices (Shavelson and Towne 2002). The first is descriptive and asks, "What's happening?" in each alternative. To describe practices, researchers may describe student characteristics with statistical estimates, draw simple relationships between programs and outcomes, or craft rich accounts through case study or ethnographic methods.

The second question, "Is there a systematic effect?", looks for *causal* effects. To answer this question, researchers seek evidence that a given practice produces the expected outcomes and may compare practices to evaluate whether one performs better than the others. In this case, randomized experiments are considered the gold standard, as long as they are authentically, logistically, and ethically applicable, but other designs such as quasi-experimental and observational (e.g., longitudinal surveys) also serve this purpose.

The third question is "Why or how is it happening?" To find evidence of a causal *mechanism* underlying the efficacy of the practice, researchers may use a variety of methods, including in-depth observation and well-controlled experimentation.

Decisions about practice should rely on all three types of evidence although the third type is rare. Realistically only evidence-based description and causal effects are typically available. This said, Cronbach (1975) reminds us that systematic effects are context dependent, facts decay with short half-lives, and even the randomized experiments are case studies. Their generalization to new contexts – student composition, teacher competence, school policy, community characteristics, and expectations – is a matter for judgment in each new setting.

Empirical research, especially social research, is an enterprise of uncertainty. Scientific research, though not perfect (e.g., *Educational Researcher*, 2002, *31*(8), whole), attempts to reduce uncertainty (or at least measure it!) and control bias by its methods. If we are to make decisions about science education practices based on evidence about effectiveness and causal mechanisms, scientific research is the best approach. This said, other scholarly traditions such as philosophy, history, and critical theory inform decisions – making clear what has been learned in the past, what assumptions and values underlie a proposed course of action, and how political and economic power influences choice of alternatives. Evidence-based practice, then, is dominant among multiple factors in determining best practice.

Decisions About Practice

Decisions about educational practice are complex. They involve multiple values and goals; are influenced by interacting social, historical, economic, and political forces; and always require trade-offs. In the best of all worlds, they are rational or at least reasonable. Rigorous empirical evidence is essential, but not sufficient. Education-practice decisions are local and practical, and – perhaps most important – they are made even though there is rarely enough evidence to clearly dictate a specific choice; they are always made with uncertainty.

Nevertheless, evidence has an important role to play in challenging the tendency to rely on familiar experience, popular wisdom, and intuition in decision making. In Michael Lewis's 2003 book *MoneyBall*, rigorous research and data analysis demonstrated that previously undervalued empirical measures ("on-base percentage" and "slugging percentage") were better indicators of success in scoring in baseball than traditionally used indicators such as running speed and bat contact. The team that used these different measures (the Oakland As) found that players with these qualities were cheaper to obtain than those in high demand because of their traditional qualities. And it worked. The As retained some high priced star players while recruiting less expensive but highly productive players to balance out the team. They put together a record winning streak and a winning season. "What works" in baseball subsequently refocused how teams recruit and overcame long-standing traditions rooted in intuition and folk wisdom rather than have an evidence base. The same is likely to apply in many situations in education.

Implementation

Decisions occur at all levels of science education – teachers, administrators, and policy makers. At all levels, empirical data need to be transformed into evidence bearing on alternative practices or interventions. This is no easy step. Even more difficult is transforming evidence into effective action. While teachers may be aware of research "out there," they seldom use it in their own practice; even if they use research, they are rarely adept at transforming scientific statements into practice (Millar and Osborne 2009). Indeed, there is a wide research-practice gap in education, and while a variety of bridging techniques hold promise for teachers, they are mostly untested on a large scale. These techniques include, for example, translating research into teaching materials or activities and testing research locally through lesson study, action research, and design research. Such techniques require expertise, resources, and commitment of a level and type for which American public education is not set up.

Similar challenges confront policy makers and school and district administrators. Policy decisions grounded in evidence-based practice are made at a distance from the classrooms in which they are implemented. Large-scale enactment of evidence-based practice in an education system with wide variation in teaching is vulnerable to inconsistent implementation. Indeed, the apparently same intervention implemented across different sites may actually vary considerably across the sites.

In *Moneyball*, the use of rigorous research came up against institutional realities. Those opposed to the new approach argued against trading star players who were underperforming based on the evidence but were nonetheless considered outstanding by the stakeholders – the fans, team, and baseball generally. Making decisions based solely on the "scientific evidence" would be "hard moves to explain to people." Evidence-based practice – in baseball, medicine, or science education – involves the use of rigorous empirical research in making decisions. Yet, making and implementing decisions is necessarily more complex, taking place in messy realities that demand consideration of practical constraints and other information.

Cross-References

- ▶ Developmental Research
- ▶ Evidence-Informed Practice in Science Education
- ▶ Longitudinal Studies in Science Education

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Evidence-Informed Practice in Science Education

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Many researchers, practitioners, and policymakers share the view that science education research should play a role in improving practice. It is, for example, often claimed that theoretical and empirical research insights ("evidence") have been drawn upon to inform the design and evaluation of curricula, teaching sequences, and activities in science education, as well as the sequencing of content in science curricula and programs ("practice"). In discussing the relationship between research and practice, it is useful to draw a distinction between the contribution of research to the design of instruction and the role of research in the evaluation of instruction (and hence in providing a warrant for recommending an action or approach). The term *evidence-informed practice*, or *research evidence-informed practice*, refers to educational practices where research evidence has been used explicitly to justify decisions. Educational practices include the design of curricula, textbooks, pedagogical activities, teaching sequences, and learning environments. The term *evidence-based practice*, or *research evidence-based practice*, refers to educational practices that have been shown to be in some sense better than other educational practices through empirical research and whose use is therefore warranted by research evidence about its outcomes.

The Historical Development of the Literature and Predominant Themes

Research on the development of people's understanding of physical and biological phenomena as a result of living in the physical and social world, and their understanding of scientific content following deliberate teaching, has been the focus of research at least since the pioneering work of Piaget and Vygotsky in the early part of the twentieth century. From the 1960s, perspectives on science learning were formulated and used to inform curriculum decisions about science, as well as the design of science teaching activities (e.g., Ausubel's *meaningful learning*, various formulations of *constructivism*, models of *conceptual change*, and *sociocultural perspectives on learning*). From the 1970s to the 1990s, a large number of empirical studies of children's, and other learners', explanations for physical and biological phenomena were conducted. These provided empirical evidence about the likely conceptual starting points of science learners when introduced to formal scientific content through teaching and how their understandings developed as a result of teaching.

During the second half of the 1980s and 1990s, the focus of research moved toward considering how empirical evidence about science learners' existing knowledge, as well as theorizations of science learning, might be used to inform decisions about the practice of science education.

Two important considerations are the *focus* of practice that research evidence has been used to inform and the *grain size* at which practice is informed. Research evidence (including both theoretical and empirical insights) has been used to focus upon decisions about the aims of teaching (such as the potential benefits to science learning of direct instruction about aspects of the nature of science), the sequencing of the curriculum and age placement of topics, and overall pedagogical approach in science education. Decisions about these have been at both a *large grain size* (such as the use of "inquiry" as a pedagogical method in science classrooms or the age placement of specific topics in national science curricula) and a *fine grain size* (such as the detailed specification of content aims and pedagogical approaches for teaching a specific science topic to learners at a given age and stage in their education). The same research evidence may be used with more than one focus and in interventions of different grain size.

A Focus on Decisions About Pedagogical Approaches in Science Teaching and Age Placement of Topics (Large Grain Size)

Jean Piaget's account of the development of reasoning in children was very influential in science education in the second half of the twentieth century. Piaget portrayed the development of children's reasoning in many areas, including their reasoning about physical and biological phenomena, in terms of the development of general logic-mathematical reasoning capability (*genetic epistemology*). Piaget proposed broad developmental stages through which all children progressed in a process of intellectual maturation (*stage theory*). Piaget's genetic epistemology and stage theory have been used by science educators with a focus on the age placement of content in science curricula from the 1960s in both North America (e.g., the Biological Sciences Curriculum Study) and the UK (e.g., Science 5–13). The approach used involved analyzing science curriculum content for the logic-mathematical reasoning skills that would be required for comprehension. Content was then placed into the curriculum so it would be taught when most students would be mature enough to learn it, according to Piaget's stage theory. During the 1990s in the UK, the *Cognitive Acceleration through Science Education (CASE)* project drew upon Piaget's genetic epistemology and proposed an approach for developing the reasoning of adolescents by teaching general logic-mathematical reasoning skills in science lessons.

Challenges to Piagetian perspectives on the development of reasoning, and their use to inform decisions about formal education, became prominent following the publication in 1968 of David Ausubel's *Educational Psychology: A Cognitive View*. Ausubel proposed that a learners' grasp of conceptual content, rather than their general reasoning abilities, determined their success or otherwise in learning in a given conceptual area. Drawing upon Ausubel's domain-specific view of learning, perspectives on science learning (e.g., *constructivism*, *conceptual change*) were advanced from the 1970s onwards. These were used to focus on the design of science pedagogy at a large grain size. For example, Posner, Strike, Hewson, and Gertzog portrayed science learning as conceptual change and made suggestions about pedagogy such as how anomalous data could be used to promote conceptual change. Driver and Oldham drew upon a constructivist perspective of science learning to advance a "constructivist teaching sequence." However, in common with much work in the early 1980s, both pieces of work tended to theorize the overall orientation of the teaching rather than details of particular activities at a fine grain size.

More recently, there have been calls to move the focus toward a theory of instructional design, rather than starting with a perspective on learning and then considering its implications for teaching. For example, in 2001 Oser and Baeriswyl proposed a theory of instructional design, based upon the sight structure of lessons (i.e., the concrete activities of students) and basis models of lessons. Basis models refer to activities to promote specific mental processes in learners such as becoming aware of what they already know about a subject. In common with the approaches discussed in the last paragraph, the design of specific teaching sequences at a fine grain size is not addressed.

All of the above research rests upon perspectives that portray science learning as involving the *acquisition* of something (such as scientific concepts or logic-mathematical reasoning skills) in the cognitive system of the individual learner. Perspectives which portray learning as a process where learners become able to *participate* in a social practice have also been drawn upon to inform the overall design of science learning environments. Researchers and designers in North America, working in the field of *the learning sciences*, have been influential in suggesting how theoretical insights about learning can be used to influence the design of science learning environments. The term "learning environment" refers to all aspects of the setting where science learning is to take place, including the resources available and the nature of the tasks that students will undertake. Such work involves or advocates the building up of learning environments over extended periods of teaching lasting for several lessons as a minimum, for the teaching of a range of science content.

Perhaps the most influential proposal for science learning environments arising from sociocultural perspectives on learning is that *inquiry* should be used as a pedagogical approach. Inquiry involves students in learning through activities that are in some sense authentic to the actual practices of professional scientists. For example, learning might take place in contexts where some problem definition is required, as part of teams with shared responsibility for making progress, with accountability to disciplinary norms. In the literature on inquiry as a pedagogical approach, the primary curriculum focus is often upon learning about aspects of the norms and practices of science rather than any particular substantive conceptual content.

The framework of *Productive Disciplinary Engagement* (PDE) was proposed by Engle and Conant in 2002 to specify more precisely how learning environments might be designed to enhance students' science learning. PDE is achieved by promoting 4 principles in the design of science learning environments, namely, ensuring that students have ownership of a scientific problem, giving them authority to address the problem, ensuring that they are responsible to others and to disciplinary norms in coming up with solutions, and making appropriate resources available for students to address the problem. However, there are as yet no published examples of the use of PDE to promote students' understanding of the substantive conceptual content of science.

Around the turn of the new millennium, the National Research Council in the USA brought together a group of experts to provide a bridge for practitioners between the available evidence on learning and the practice of teaching. The products of this work were published in the 2005 book *How People Learn: Brain, Mind, Experience and School* and are summarized in three principles together with a framework of 4 "lenses":

Principles

- Engaging prior understandings
- The essential role of factual knowledge and conceptual frameworks in understanding
- The importance of self-monitoring (i.e., metacognition)

Framework

- The learner-centered lens (encouraging attention to students' existing knowledge and beginning instruction with what students think and know)
- The knowledge-centered lens (focusing on what is to be taught, why it is taught, and what mastery looks like)
- The assessment-centered lens (emphasizing the need to provide regular opportunities for both teacher and students to reflect on the progress of learning)
- The community-centered lens (encouraging a culture of questioning, respect, and risk-taking)

The principles and framework of *How People Learn* were developed by drawing upon both acquisition and participation metaphors for learning and empirical evidence about how individual learners think about particular problems. They provide guidance on the design of learning environments at a large grain size.

A Focus on Decisions About Pedagogical Approaches and the Sequence in Which Ideas Are Introduced in Teaching (Fine Grain Size)

There is also a significant literature on the use of evidence to inform the practice of science education at a finer grain size, including the design of pedagogical approaches to "teach x" to students of a given age and stage in their science education, where x is a specific piece of scientific content. Such research is usually named with some form of the word *didactics* in (non-Anglophone) European languages and addresses questions about what content to teach, why to teach it, who to teach it to, and how ideas should be introduced and built upon in short teaching sequences. During the 1980s, research programs were developed in centers around the world where an important research aim was to develop research evidence-informed practice about "teaching x" (e.g., the works of Fensham, Gunstone, White, and colleagues in Australia; Bell, Freyberg, and Osborne in New Zealand; Lijnse and colleagues in the Netherlands; von Aufschnaiter, Duit, Fischer, Niedderer, and colleagues in Germany; Tiberghien, Séré, Viennot, and colleagues in France; Driver and colleagues in the UK; Arons, Clement, McCloskey, McDermott, Minstrell, and others in the USA). During the 1980s, a number of longitudinal studies of how individual students developed their understanding of scientific phenomena through a program of teaching were also conducted.

These programs of work led to two fundamentally different kinds of product. The first were detailed empirical and theoretical accounts of students' reasoning in various domains of science content learning (together with guidance about practice, including the most appropriate and feasible aims for teaching particular scientific ideas to students of different ages and at different stages of science education, and the most rational approach to introducing linked ideas in teaching sequences). The second product was materials to be used to teach content to students and assess their progress. These research programs were initially developed in several different languages, with the consequence that the development of theory and terminology across research programs was somewhat limited.

From the 1980s until the present day, several approaches to designing and evaluating pedagogical approaches to "teaching x" have been elaborated and refined. The theoretical and methodological basis of approaches has, in some cases, been developed across science and mathematics education. In 2003, a themed issue of the journal *Educational Researcher* presented work from the design-based research and learning sciences communities in which the primary focus was typically to produce sequences of teaching activities together with a domain-specific instructional theory specifically to inform the process of design (Educational Researcher 2003; Leach and Scott 2008). Various authors of papers in the themed issue noted that their approach involved *implementing* an existing design, rather than the process of *generating* the design itself. Authors also noted the difficulty of communicating the outputs of design-based research, with the result that academic outputs targeted at mainstream educational research audiences tended to focus on methodological and conceptual issues rather than substantive products. They also noted that the design process (as well as the designed teaching itself) is always underdetermined by theoretical insights. A more recent collection, edited by Kelly and colleagues (2008), presents further work from the learning sciences community

In the Netherlands, *developmental research* was proposed by researchers in the Freudenthal Institute for Science and Mathematics Education at Utrecht University. The approach involves the production and refinement, through successive iterations of design and implementation, of "teaching scenarios" with the intention that they are progressively improved in "didactical quality." *Educational reconstruction* was developed at the Leibniz Institute for Science and Mathematics Education (IPN) at Kiel University, and at the University of Oldenburg, in Germany. Educational reconstruction involves reconstructing scientific concepts for the purpose of education, by developing links between scientific concepts about phenomena, and learners' everyday reasoning about the phenomena described by those concepts. Educational reconstruction has been used to inform the development of teaching sequences in various content areas of science, as well as to inform the presentation of material in textbooks. Working in Paris, Viennot and her colleagues draw upon empirical evidence about science students' characteristic ways of thinking about a given content domain in physics, as well as the historical development of physics concepts, in the design and evaluation of detailed teaching approaches in physics. Other researchers in France have developed various theoretical tools to inform the design of mathematics and science teaching on the basis of an *anthropological theory of knowledge*. These include the *theory of didactical situations* and *didactical engineering*. These theoretical tools have been used in the design and evaluation of teaching about various scientific concepts, particularly by Tiberghien and her colleagues working in Lyon.

Some work at a fine grain size has focused on assessment as a tool for stimulating changes in teaching, rather than proposing specific teaching interventions. The *Force Concept Inventory (FCI)* in the USA was developed from detailed empirical insights about students' characteristic ways of explaining phenomena, where physicists' explanations draw upon the concept of force. The FCI has been used as both a tool for formative assessment and a stimulus to teaching approaches. Along similar lines, Millar and colleagues in the UK have produced detailed formative assessment items drawing upon empirical evidence about students' explanations in various areas of science.

Much of the evidence used to focus on the design of teaching at a fine grain size has also been used at a larger grain size to focus upon overall design aspects of the science curriculum. For example, many curriculum documents claim that evidence about students' likely conceptual starting points at the beginning of teaching of specific science topics was used to inform curriculum decisions. By the mid-1990s, several studies of the *conceptual trajectories* or *learning trajectories* followed by individual learners had been completed around the world; claims have been advanced that evidence from these has been drawn upon to inform decisions about the age placement of topics. However, due to the fact that examples were produced in various languages, and the length restrictions of academic journals, the details of how this was done tend not to be included in publications.

In a recent paper synthesizing literature on research evidence-informed approaches to teaching science and mathematics content at a fine grain size (included as further reading), Ruthven and colleagues (2009) suggest that three different types of theoretical insights have been used:

- *Grand theories* about learning or epistemology (such as Piaget's genetic epistemology; Bachelard's theory of the development of knowledge) provide an overall orientation to the aims and desired outcomes of educational practice.
- *Intermediate frameworks* (such as the theory of didactical situations or a social constructivist perspective on learning science in formal settings) are developed from grand theory and other influences (such as empirical evidence about students' likely conceptual starting points in a given content domain) to inform an educational practice (such as designing pedagogical approaches to "teaching x" at a fine grain size).
- *Design tools* are developed from intermediate frameworks to inform design decisions at a very fine grain size.

The design tools *knowledge distance* and *modeling relations* were developed by Tiberghien and colleagues to inform decisions about the scientific knowledge to be taught and the relationships between knowledge that need to be made explicit during teaching, respectively. Leach and Scott elaborated an intermediate framework entitled *a social constructivist perspective on science learning to inform science teaching in formal settings*, with the specific aim of informing the design of teaching scientific content at a fine grain size. They developed the design tools *learning demand* and *communicative approach* to inform, respectively, the specification of science content goals for the purpose of teaching and the "staging" of pedagogical activities in the classroom. Research evidence-based teaching sequences have been designed and implemented, with evaluation focusing on both the success of the teaching sequence in achieving its specified aims, and the success of students in understanding the conceptual content that the teaching focused upon, compared to their peers following the school's conventional approach.

The research outlined above was developed in parallel, with few attempts to integrate products of the research cumulatively. When examining the literature on "teaching x," it is striking how many papers state that it is not feasible to specify fully the products of the research in academic papers. There are at least two possible reasons for this. The first is the difficulty of communicating the findings of research on "teaching x" at a fine grain size, particularly when the curricula in different countries include different scientific content at different ages and stages of education. Secondly, insights from the research are often embedded in materials to be used in practice, rather than written down for the purpose of communication between researchers and designers.

Cross-References

▶ Developmental Research
▶ Didactical Situation
▶ Evidence-Based Practice in Science Education
▶ Learning Progressions
▶ Model of Educational Reconstruction

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Educational Researcher (2003), 32(1). This edition of the journal includes several articles on design-based research. Although the focus is mainly on mathematics education, when taken together the papers give a comprehensive account of methodological and substantive issues in design-based research that is directly relevant to science education.

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Excursions

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While excursions can take many forms and extend over a range of time periods, here excursions are defined as one-off school visits, generally lasting a single day or shorter, to informal science settings, particularly locations such as museums, nature and science centers, zoos, aquaria and botanic gardens, local and state parks, planetaria, or science fairs and festivals. The traditional excursions, or field trips, need to be distinguished from other forms of out-of-school learning, such as service learning, citizen science, and ongoing experiences like science clubs or tending a school garden that provide sustained and repeated opportunities for engagement and learning. However, many of the points made below about learning outcomes, factors impacting learning from field trip experiences and the ways in which informal science education experiences during organized excursions can support learning, are applicable to a wider range of settings and types of experiences (e.g., visits to amusement parks).

Excursions offer a range of features that distinguish them from classroom lessons and that may contribute to a range of desired learning outcomes. For instance, they can allow for increased student interaction and responsibility. They also provide exposure to novel experiences and authentic objects. While they can (and oftentimes have to) link to the school curriculum, they also support engagement with new content, contexts, and experiences – and familiar content presented in ways not necessarily possible in the classroom. Put differently, they are not necessarily "better classroom experiences" but rather offer valuable opportunities to complement or extend classroom learning. Indeed, excursions are perhaps most supportive of learning when they are connected to school experiences via pre- and post-visit activities.

Learning Outcomes

Decades of research on school field trips has investigated ways in which these experiences can lead to learning and has explored different types of learning outcomes and conditions that maximize this learning. The original focus of much of this research was on cognitive or conceptual gains, based on perceptions that field trips had to be competitive with classroom instruction in order to be of value. While such experiences can certainly lead to cognitive outcomes, such as understanding and knowledge of facts and concepts, these gains are often quite small and dependent on the degree to which students were readied to engage with content and on designing field trips to focus heavily on specific learning goals. Evidence suggests, however, that school trips are often better suited to reinforcing, or even extending, existing understanding, rather than introducing new concepts. There is also emerging evidence that field trips could provide the foundation for future learning. That is, exposure to a concept during a visit, particularly if experienced directly, can increase the likelihood of deeper learning about this concept when it is reencountered in another environment, such as a classroom.

While major and measurable cognitive gains tied to scientific concepts are difficult to achieve during the short time span of most excursions, other important outcomes are more likely to occur, including exposure to and awareness of ideas or even the trip setting and a range of what are now increasingly being referred to as "21st Century" skills: affective outcomes and social outcomes such as inter- and intrapersonal learning. Indeed, research has documented that school trips can be positive affective and social experiences for students (and teachers), leading many in the field to advocate for the value of these visits in encouraging motivation and sparking interest, as well as supporting exploration and social interaction, both among students and between students and teachers. In addition, extensive research in learning and psychology has highlighted the way in which motivation (especially intrinsic) and interest can lead to conceptual gains. Thus, although school trips may not provide ideal conditions for introducing new concepts to students, they can certainly support even new learning indirectly.

Factors Impacting Learning

There is a variety of factors that can impact the effectiveness of excursions as cognitive, affective, or social learning experiences. For instance, the novelty of a setting can distract from learning as students orient themselves in an unfamiliar environment, highlighting the importance of an orientation prior to the trip. Another important element that can influence what individuals learn, especially cognitively, from a school visit is their prior knowledge about topics and concepts encountered on the trip. When the exhibits and programs encountered connect to and build upon this previous knowledge, learning is enhanced. Making these connections can be difficult, due to the wide range of previous knowledge and experience visitors bring, but teachers can help students to make them if they themselves know what to expect during the field trip and have opportunities to prepare students accordingly.

Another key feature of school trips involves social interactions, among students and between teachers and students (and chaperones, explainers, or docents). This aspect of excursions is memorable and highly valued by students, and interactions – such as small group work and discussions – can contribute significantly to learning, affective, cognitive, and social. Learning is further enhanced when these school visits are responsive to the interests, motivations, and agendas of students.

The Role of Structure

Structure is another key element influencing learning from excursions. Generally, structured experiences (i.e., guided tours, worksheets, specific detailed tasks) can increase cognitive or content learning but often dampen interest or other affective outcomes. However, recent research suggests that well-designed resources, including worksheets, can support both cognitive and affective learning. Worksheets are more effective learning tools when they allow for free-choice exploration; encourage observation, exploration, discovery, and discussion rather than explanations and answers; connect to the curriculum; and focus on objects rather than labels. Field trips are most likely to connect the cognitive, affective, and social domains of students when constructed as opportunities for original experiences and discovery and are least likely to do so when they simply mimic the classroom environment.

Accordingly, a moderate amount of structure seems most likely to maximize the learning potential of field trips. A recent study found that visits offering limited choices to students – involving a structured task but simultaneously allowing some choice and control in exploring a setting – were more engaging than either highly structured or unstructured visits. "Limited choice" trips also seemed to support content learning, encourage deeper involvement, and promote social interactions. Highly structured or mostly unstructured field trips tend to miss building on the opportunities of an out-of-school setting.

The structure of an excursion extends beyond the visit itself to incorporate what happens prior to and following a visit. Although it can be very difficult for teachers to provide extensive preparation and follow-up, research highlights that pre- and post-visit activities in the classroom are critical to maximizing the cognitive, affective, and social learning that can field trips can provide.

Teachers and Schools

Teachers play a critical role in the success of school trips as learning experiences. In order to support learning, teachers have been encouraged to (a) become familiar with the trip setting prior to the visit, (b) orient students to the setting and clarify learning objectives, (c) encourage at least some free exploration during the visit, (d) plan curriculum-related activities that also take advantage of unique features of the trip setting, and (e) implement pre- and post-visit activities to support and reinforce the visit experience.

Although teachers generally want to maximize the learning opportunities offered by school trips, implementation of the recommendations above is curtailed by the contextual and institutional constraints they face, such as time, testing regimes, demands for explicit curricular connections, and other logistical restrictions, and is also hampered by lack of appropriate expectations and pedagogical vision for the affordances that field trips can provide. Consequently, it is argued that informal science institutions have an important role to play in facilitating good practice among teachers, particularly via the provision of resources. Such resources may be constructed in a variety of formats (e.g., web or paper based) and should facilitate behaviors likely to support learning, such as discussion. However, in order to be utilized by teachers in the first place, they should be codeveloped with teachers and with the teacher's context in mind – including their goals or objectives for the visit, their current practices on visits, curriculum requirements, and logistical hurdles. For instance, even when teachers recognize that the trip setting offers unique opportunities for learning, they may be unsure as to the best way to capitalize on those opportunities or to construct rich opportunities for learning and discovery that are clearly tied to the school curriculum.

Nevertheless, there is an ongoing debate in the field as to whether institutions should connect their programs, activities, and exhibits to the curriculum or whether they should focus on their unique affordances. It would seem that, as with the degree of structure, an intermediate solution is most likely to be effective. That is, in order to support teachers in maximizing the learning opportunities, both cognitive and affective, offered by excursions, supporting resources should both highlight the new and connect to the curriculum while respecting the contextual issues faced by teachers and schools. More importantly, rather than recreating school-based learning, out-of-school settings should provide curriculum-relevant experiences that focus on their unique affordances of material, places, or expertise.

Benefits to Science Education

A substantial body of research on school trips has repeatedly indicated that even short-duration excursions can support learning, both cognitive and, especially, affective. Informal educators and teachers alike value these experiences for the opportunities they provide to enhance motivation, spark interest, and encourage social interaction and to access original and authentic settings, objects, and experiences. Learning on and from excursions and field trips is not simply an extension or improvement on classroom lessons, but is an important complement to school instruction and a way to prepare students for future learning experiences. At the same time, in order for the benefits of school trips to be fully realized, it is critical that informal institutions support and scaffold good teacher practices around these experiences.

Finally, although there is considerable evidence of the benefits for science learning provided by excursions, documenting long-term impact continues to be a challenge for the field, though some studies on long-term memory, seeking subsequent reinforcing experiences, or preparation for future learning suggest that field trips can have lasting impacts. Long-term impacts from short-duration field trips are certainly difficult to measure and likely to be idiosyncratic and given the nature of learning as incremental and resulting from the interweaving of many experiences over time, hard to attribute to a specific past experience. Nevertheless, both short- and long-term impacts on learning are most likely when visits are linked to classroom instruction and supported by pre- and post-visit activities.

Cross-References

- ▶ Aquaria
- ▶ Botanic Gardens
- ▶ Explainer
- ▶ Industry Visits
- ▶ Interpretive Centers
- ▶ Learning Science in Informal Contexts
- ▶ Museums
- ▶ Out-of-School Science
- ▶ Planetaria
- ▶ Science Exhibits
- ▶ Visitor Studies
- ▶ Zoological Gardens

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Experiments

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Keywords

Intervention; Hypothesis testing; Practical work

The word "experiment" is used in different contexts to mean different things. School pupils, in the UK anyhow, often use it to mean any practical activity that they undertake in a science lesson. Teachers and science educators often talk about "experiments" in a similarly general way. Practical activities used in science teaching, however, differ widely in their aims and purposes and not all are "experiments."

The philosopher of science, Ian Hacking (1983), characterizes an experiment as an intervention – where someone (a scientist or a school student) does something in order to create a phenomenon that can then be observed, either qualitatively or quantitatively (by making measurements). This contrasts with situations where data are collected by observing an event or phenomenon that is happening anyhow. In some sciences (physics, chemistry, some aspects of biology), experiments are the dominant form of investigation. In other sciences (astronomy, geology, ecology, paleontology), data are obtained principally (or entirely) by observation; no intervention is necessary (or, indeed, possible) to create the phenomenon of interest.

An "experiment" in this sense does not have to be carried out in a laboratory; it might be undertaken in the field, or in a classroom, or kitchen, or playground. The key criterion is not where it takes place but whether you have to do something to create the phenomenon you are interested in and hence generate data, or can simply observe what is happening, or what exists, anyhow. This usage is quite close to the everyday sense of an "experiment" as "trying something out to see if it works," or perhaps simply "to see what happens."

The word "experiment" is, however, often used with a more specific meaning – as a procedure carried out to test a hypothesis. Carey et al. (1989), for example, used a teaching intervention to encourage middle-school students in the USA to move toward seeing an experiment as a test of a hypothesis. Duveen et al. (1993) similarly sought to encourage students to think of scientists using experiments for "testing explanations," rather than for "making discoveries" or "making helpful things." The principal aim behind this sort of work is to help students appreciate that experiments are purposeful, not simply speculative actions "to see what happens." A hypothesis-testing perspective reflects the centrality of theory and explanation in science and may help to develop students' understanding of the relationships between data and explanation.

Nonetheless, we should perhaps acknowledge that many of the practical investigations which scientists undertake are not designed to test a hypothesis. This is particularly true when a scientist is investigating a new topic or area which is not yet well understood. But it is also the case in more established areas of science. The work of Franklin, for example, to take X-ray diffraction images of DNA that were critical underpinning for Crick and Watson's proposal that the molecule had a double helix structure certainly involved an intervention (the data had to be generated; they were not there waiting to be collected). Taking a diffraction photograph could be regarded, in Hacking's terms, as an "experiment," but could not really be said to be testing any hypothesis. Many other similar examples could be cited.

The word "experiment" also has a rather specific usage in social science – and one which is closer to the "hypothesis-testing" sense of the word. Here an "experiment" means a research study that involves comparing one group that has had a particular experience or "treatment" (the experimental group), with another (the control group). The purpose of an experiment is to provide evidence that a specific factor (the thing which is different for the experimental group as compared to the control group) has, or does not have, an effect on a particular outcome. A classic paper by Campbell and Stanley (1963) discusses the range of experimental designs that can be used in research on teaching and their strengths and weaknesses.

A range of meanings, and nuances of meaning, of the word "experiment" suggest that, in science education research, it may often be better to use a different term (such as "practical work" or "practical activity") to describe the thing we are interested in. If the word "experiment" is used, it may be helpful to say explicitly what it is being taken to mean.

Cross-References

- ▶ Laboratories, Teaching in
- ▶ Laboratory Work, Forms of
- ▶ Laboratory Work: Learning and Assessment

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Explainer

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Explainers, educators, facilitators, mediators, pilots, guides, helpers, science communicators, whatever their name is in the different institutions, these professionals have an essential role in science centers and museums, as well as in the informal learning programs of natural parks, botanical and zoological gardens, aquaria, etc. Often they are the only human, direct interface between the institutions and the public, so being the key element in determining the quality of visitors' experience. Students and young researchers are employed in a similar role in science festivals and outreach activities of research institutes and universities, so that all around the world those human interfaces have a relevant impact on the whole of science and technology public engagement.

Explainers have a wide range of tasks: they greet the visitors; guide them through permanent galleries, temporary exhibitions, open-air promenades, or open-day stands; provide information and help people interpret what they see; and run science shows, scientific demonstrations, and interactive workshops. In hands-on exhibitions, they stand near the exhibits ready to facilitate visitors' interaction and learning. In conservative museums, they help visitors to make sense of the displayed objects. More recently, explainers have also been the facilitators of discussions on controversial scientific issues, in the context of science cafés, board games, role-plays, scenario workshops, or other participatory formats.

But who are they? Is there a clear definition of their role and tasks? How are they selected and trained? Which kinds of contract link them to the institutions? In which kinds of internal organization structures are they placed? And do the answers to those questions differ depending on institutions and/or countries, or are they shared at large?

For many years, explainers' presence has been largely taken for granted and little reflection given to their role in facilitating science and technology public engagement. Institutions such as the Exploratorium of San Francisco have promoted for decades the internal explainers professional development, experimenting with effective and innovative training schemes; but, besides those best practices, only a very small number of studies and surveys has explored their professional role and status. In the last few years, however, greater attention has been given to these practitioners, and the issues related to their professionalization have started to be discussed in congresses and highlighted in papers. More important, reflections and practices are more and more shared among an enlarging, international community.

Most explainers are doing this work as a temporary job while completing their studies or waiting to find another job. The temporary nature of the work determines in many cases the nature of the contracts: many explainers are paid by the hour, generally receiving a low salary (Rodari and Merzagora 2009). This precarious status (young age, rapid turnover, low salaries) is probably the cause, in many situations, of an insufficient investment in their training. But a recent study shows that more and more explainers are on the contrary not so young, have a strong scientific background, and tend to stay in the job for longer periods, if not for their whole working life (Richard and Barrett 2011). On the other hand, the temporary nature of the explainer's position is not necessarily negative. Working as an explainer is an extremely gratifying experience, allowing young people to transmit their passion for science in the direct contact with various audiences (Bailey 2006; Rodari and Merzagora 2009). This experience, and the acquired communication and teaching skills, will be of use in the future when the explainers become researchers, professionals, or teachers, a job's side effect exploited in some international experiences. The Slovenian science center Hisa Eksperimentov, for example, trains and employs university students of the University of Ljubljana, as a recognized part of their degree course. In the USA, the Science Career Ladder program of the New York Hall of Science provides meaningful work experience as explainers to high school and college students, as a way to engage them with science in the perspective of a scientific career. Those pupils and students, acting as explainers, become also science ambassadors for their peers and for “hard-to-reach” audiences, therefore being a precious tool for a better social inclusion.

For those explainers who wish to progress within their institutions, there are rarely well-defined career paths. Possible exceptions are the UK and the USA, where, also in the absence of a clear profession recognition, many people who started to work as explainers are later given major responsibilities in the education or exhibitions departments.

The majority of institutions do not organize a proper training course for explainers when they enter into service, or they merely hold short introductory meetings (Rodari and Merzagora 2009; Richard and Barrett 2011). In most of the cases, the training consists only in the so-called “shadowing,” i.e., the young explainer following and then imitating a senior colleague. Theoretical training in science communication and informal education is almost always missing (Tran and King 2007).

The lack of thorough practical and theoretical preparation makes it difficult to come up with a clear definition of the role of explainers and means that they lack a common language with which to speak about themselves: “It happens ordinarily that someone asks me ‘what is your job?’. I can describe my job but I don’t have the word for my job. There no words: I’m not a teacher, I’m not a researcher, I’m not a guide.” For some, the only way to define themselves is to describe the place where they work: “I work in a science center” (Merzagora and Rodari 2009). In addition, it becomes just as difficult to construct a reference system to assess the performances of explainers and their impact on the public (Tran and King 2007).

Not only the names given to the explainers are various in the different institutions (Rodari and Xanthoudaki 2005), but also the structures in which they are organized can vary. In some institutions people who design activities and people who deliver them are different. In others, the same people are in charge of all tasks.

Despite the local differences, lack of training, and lack of a common theoretical background, explainers identify strongly as a group, even when they come from institutions that are far apart geographically, economically, and culturally (Bailey 2006; Tran and King 2007; Rodari and Merzagora 2009; Richard and Barrett 2011).

The growing awareness of explainers’ importance in the public engagement of science has stimulated many action/research projects aiming at the identification of their training needs (http://www.dotik.eu; http://www.thepilots.eu; http://www.dialogueacademy.org.uk/). The professional profile of the explainers is emerging as incredibly complex.

To work as an explainer requires, besides a good scientific and technological understanding, many and various communication skills, so these skills are prioritized during staff selection. In order to perform demonstrations and science shows, explainers need the body and voice control of an actor and the ability to attract visitors’ attention with meaningful, spectacular experiments organized in well-prepared scripts. In other contexts, such as leading workshops or on-floor dialogues with the visitors, the explainers need considerable flexibility and creativity, to react to changing situations, diverse people, and unexpected events. Being the leaders of the activities, the explainers must be able to leave the stage as much as possible to the public. A good explainer “does not explain” but promotes interaction from the visitors or even, ideally, induces “some kind of ‘scientific behavior’: observation, questioning, manipulation, experimentation, critical evaluation of statements and answers” (Gomes Da Costa 2005). Today, explainers are asked to facilitate *inquiry-based learning* activities that require sophisticated relational and pedagogical skills.

Activities must be adapted to the different audiences, so that the capacity of listening and understanding people is essential, as well as the management of cultural differences (ethnic, religious, ideological, socioeconomic, etc.). Explainers are asked to promote respect and understanding among different cultures, stimulating communication among different communities: “In serving as liaison, cultural broker, and experimenter, the educator is ‘in’ the crossroads of staff and community exchanges that contribute to deepening civic engagement” (Henry 2006). Following a general development of the museums’ mission, the focus of explainers’ work is switching from the centrality of objects, exhibitions, and topics to the centrality of people and their learning needs.

Finally, the explainers should contribute to the promotion of a public *science governance*, becoming facilitators of the dialogue between science and society. This requires for the explainers to acquire new skills, new theoretical awareness, and the knowledge and practice of the new event formats that have been developed in the last years, such as discussion games, role-plays, and scenario workshops (Rodari and Merzagora 2009).

Considering this complexity, is it possible to arrange all these required competences in a professional development scheme, applicable to all institutions? Is it possible, even more, to design and propose a standardized, higher education level, course of studies? The discussion on this point is rich and still ongoing (Bevan and Xanthoudaki 2008; Tran and King 2007; Tran 2008).

The professionalization of explainers would allow them to acquire cultural (and also economic) external and internal recognition. To define its standards of quality and the methods to assess them would be also much easier.

There are two possible interpretations of this professionalization process. With a bottom-up approach to the problem, many European institutions organize international training courses in which sharing of experiences and knowledge gradually leads to an international learning community, still very fluid in practice, but with a growing awareness and reciprocal knowledge. The advantages of this approach are many. An increasing number of explainers are gaining the feeling of being part of a community; they are aware of debates and trends inside the museums or science centers community; they are able to meet people from all over the world and share practices and reflections; they are acquiring new skills and competences. Best practices, always existing, can be finally shared among different institutions, and international training schemes can also be applied locally, so that less experienced institutions can learn from the most experienced.

A “hard” interpretation of the professionalization process, however, leads to a single, complete as possible, training scheme, offered by higher education institutions and largely recognized all around the world. This hard approach presents not only advantages but risks (Bevan and Xanthoudaki 2008). The advantages comprise a stronger external recognition of the explainers’ profession and surely better career opportunities for practitioners. Main risks include:

- Loss of the variety of people now acting as explainers, such as secondary school pupils as well as retired people, with all the richness this diversity offers.
- Loss of the variety of practices, created by institutions with different histories and cultures; a variety that constantly produces new formats of activities.
- Stopping change: because science and technology communication practices (and also theoretical reflections on the field) are changing so fast, it may be difficult for an institutional course to keep pace.
- Reducing the distance from school educators. Many higher education institutions do not have updated competencies in informal learning and science communication; the institutionalization of the explainers’ training would therefore risk bringing their profession too close to the one of school teachers, losing the innovation present in explainers’ informal approach.
- Exclusion of explainers from the definition and development of their own professional profile. In the bottom-up approach, those processes involve explainers as proactive actors, and the peer-to-peer learning is key element of the training best practices. Would be this role guaranteed if universities and higher education institutions take the lead?

The current discussion on the explainers' professionalization, linked as it is to the debates concerning social inclusion and public participation in science and technology governance, is in itself an agent of change, fostering the awareness of this community of people toward a more complex understanding of the role of science and technology in society.

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Explaining as a Teaching Strategy

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Keywords

Argument; Claim; Proposition; Slowmation

An explanation is a statement or set of statements that clarifies the reasons, causes, context, or principles that underpin a particular phenomenon. The word derives from the Latin term explicatus, which means to provide reasoning for. Explanations are central to the discipline of science as one of the goals of the discipline is to provide explanations that lead to a deeper understanding of various phenomena. In plain English, explanations elucidate why things work, what something is, or how things happen. They often provide cause and effect relations, include a time sequence, and use action verbs. An explanation usually has five parts: (i) naming or specifying the concept, (ii) describing elements or components of the concept in an appropriate order, (iii) explaining how the elements relate or connect to each other, (iv) providing an example, and (v) summarizing with a concluding statement.

It is a fundamental expectation in most school science curricula that students should be able to explain science concepts. For example, the Australian National Curriculum states: "Science provides an empirical way of answering interesting and important questions about the biological, physical and technological world. The knowledge it produces has proved to be a reliable basis for action in our personal, social and economic lives" (ACARA 2012, p. 3). Similarly, the US National Science Education Standards calls for more than "science as process," in which students learn such skills as observing, inferring, and experimenting. "Inquiry is central to science learning. When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. In this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills" (1996, p. 2).

Types of Explanation

There are many types of explanations, including deductive-nomological, functional, historical, psychological, reasoning, rationalization, consequential, causal, and argumentation. In line with the commonly acceptable deductive-nomological model, a scientific explanation has two parts: (i) the explanandum is the phenomenon that is to be explained and (ii) the explanus is the evidence, reasoning, or details to explain the phenomenon. According to Hempel (1965), "the explanus must be a logical consequence of the explanandum" and "the sentences constituting the explanus must be true" (p. 248). So the explanandum identifies the concept or phenomenon being explained, and the explanus provides the evidence or reasoning. For example, someone may ask a question about a weather phenomenon such as "what is a tornado?" which is an explanandum, and a reply could be "an intense low pressure system that has rapidly rotating air like a spout," which is an explanus.

Another type of explanation is based on the notion of argumentation (Toulmin 1969). An argument has four components: (i) a claim which is an assertion or conclusion about a particular phenomenon, (ii) evidence which is the data that supports the claim, (iii) warrant which is the status of the evidence so that it is adequate and valued by others, and (iv) reasoning which is the line of thought linking the claim and evidence.

Teaching Strategies to Promote Explanations.

Four examples of teaching strategies aimed at promoting explanations:

1. Making the Explanation Explicit

   One way is for teachers to make what is required in an explanation explicit according to a five-step procedure (McNeill and Krajcik 2008): (i) making the framework explicit by being clear to students the type of structure of explanation needed; (ii) modeling and critiquing explanations whereby teachers show students examples of good explanations; (iii) providing a rationale for creating explanations so that students know why they need to be clear about their reasoning; (iv) connecting to everyday explanations meaning that the reasoning is based on common sense; and (v) assessing and providing feedback to students meaning that will only improve their explanations if they get explicit suggestions on the strengths and weaknesses of their reasoning.

2. Writing Scientific Explanations

   It is important that students are provided with frameworks for explaining science concepts. These have been called informative texts and can have the following parts: (i) write an introduction clearly stating the problem or question, (ii) write a sequence of steps or results which may involve providing evidence, (iii) write an implication, and (iv) write a conclusion.

3. PEEL (Project for Enhancing Effective Learning)

   One of the central goals of PEEL (a community of practicing teachers, primarily based in Australia) is to devise and implement practical teaching strategies to support student learning (Baird and Northfield 1992). Many of these strategies relate to improving student explanations, whereby teachers collect and reshape ideas from students, offering a "story" and providing students with new words to be practiced. Some of the suggested strategies are:

   - POE (Predict, Observe, Explain): Students predict what is going to happen when they see a demonstration, observe what happens, and then explain the phenomena individually or in groups.
   - Concept maps: Students summarize a discussion with a conceptual diagram or map. A concept map typically organized around a central term or idea, with other related terms extending from it.
   - Postbox: Group members each write an explanation of a concept on a piece of paper. These are passed around the group or swapped with other groups, and then each group decides which is the best combination of suggestions for the explanation.

4. Digital Representations

   Increasingly students are using their own digital technologies such as mobile phones, iPads, and computers to create digital representations to explain science concepts. They can make podcasts (audio explanation), video (audio and image), as well as animations (see slowmation) to explain science concepts. These can be shared with others by uploading to Internet sites such as YouTube or "60 s Science" or "Scientific American." See www.digiexplanations.com for examples and instructions for how to make five forms of digital explanations.

Conclusion

Explaining how the world works or why something happens is a key feature of the discipline of science. Students at universities and in schools should be encouraged to explain science in their own words as a way to develop conceptual clarity in their own understandings. When students plan for an explanation, they should take into account the purpose, audience, context, and medium so that what they are explaining becomes clearly understandable by others.

Cross-References

- ▶ Argumentation
- ▶ Concept Mapping
- ▶ Concept Maps: An Ausubelian Perspective
- ▶ Project for Enhancing Effective Learning (PEEL)
- ▶ Slowmation

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F

Facts, Concepts, Principles, and Theories in Science, Assessment of: An Overview

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Facts, concepts, principles, laws, and theories are components of science information. Inferences are made regarding individuals' knowledge about and understanding of these components based on those individuals' responses to assessment items or teachers' questions.

Measurement of knowledge about and understanding science information is challenging for several reasons. One challenge relates to the difference between knowing about and understanding. A second challenge relates to the fact that knowledge about and understanding always involves the measurement of abilities. A third challenge relates to differences in how these components are labeled and defined in the science education literature.

Knowledge about components of science knowledge typically is measured using multiple choice or constructed response items. For instance, knowledge of the boiling point of water could be measured by requiring an individual select 1,000 °C from five temperatures in response to the question: what is the temperature at which water boils at sea level? Using a constructed response item type, the individual would be required to write 1,000 °C. Knowing about a concept, principle, law, or theory can be assessed in a similar fashion simply by asking individuals to identify the definition of a concept, identify the statement of a principle or a law, or identify the natural phenomena a theory explains. For instance:

Concept: What is the definition of the density of a substance?

Principle: What is Newton's second law?

Law: What are examples of natural phenomena Newton's laws are used to explain?

Theory: What examples of natural phenomena kinetic molecular theory are used to explain?

Demonstrating knowledge of a component is a relative simple task, requiring only recognition or recitation. Demonstrating understanding is more difficult requiring additional knowledge and abilities such as knowing the empirical and theoretical foundations of the fact, concept, principle, law, or theory or the ability to construct, to identify, to evaluate an explanation using the component, or to apply the component to a theoretical or practical problem.

For instance, understanding the fact that water boils at 1,000 °C might be measured by asking why the boiling point of water is different at sea level from the boiling point on Pikes Peak. A measure related to an everyday situation would be to explain why it takes longer for a potato to cook in boiling water on Pikes Peak than at sea level.

As these examples of the measurement of knowing and understanding illustrate, successful performance items designed to measure only knowledge and understanding also measures abilities. Responses to all items require generic

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abilities such as the ability to read and follow direction. Responses to items also require science-specific abilities such as the ability to identify and evaluate a scientific explanation.

Conversely, items designed to measure abilities such as practices (NAEP and NRC Framework), cognitive skills (TIMSS), or competencies (PISA) also measure knowledge and understanding of components of science information, for instance, the TIMSS cognitive ability assesses reasoning about knowledge related to a content domain (biology, chemistry, physics, or earth science).

Even items designed to measure only what an individual knows or what an individual can do inevitably measure both knowledge and abilities.

A further challenge is that the assessment literature and frameworks for large-scale science assessments typically describe information components using familiar words: fact, concept, principle, law, and theory. However, the words are often used to mean different things. This is especially true of the word "concept." The word "concept" sometimes refers to a single entity, such as energy, organism, or system. Concept may also refer to the relationship between two or more entities. For instance, statements such as energy is conserved in closed systems are sometimes called concepts. In some of the assessment literature, statements of relationships among entities are called principles. The challenge is deciding if the word concept represents a single entity or a statement describing a relationship between or among entities.

While measurement of what individuals know seems relatively straightforward, distinctions between depth of knowledge, conflation of knowledge and abilities in the demonstration of what is known, and differences in how the components of science information are labeled pose challenges to answering the question: what is being measured.

Cross-References

- ▶ Assessment: An Overview
- ▶ National Assessment of Educational Progress (NAEP)
- ▶ Nature of Science, Assessing of
- ▶ Programme for International Student Assessment (PISA)
- ▶ Theories of Science, Assessing Understanding of
- ▶ Third International Mathematics and Science Study (TIMSS)

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Family Learning

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Defining family learning It is challenging enough to independently define the words "family" and "learning"; understanding the meaning of the two words together only complicates matters. Despite this challenge, the notion of a family learning together makes great sense given that humans learn through group interaction, conversations, gestures, emotions, and watching one another. The very first learning group a person belongs to is her family, and this group is so important that anthropologists, sociologists, and social psychologists refer to the family as an educational institution, without the bricks and mortar.

Family members engage in family learning over their lifetime through the processes of social interaction, collaboration, and sharing among members. Knowledge and understanding is constructed by the family and incorporated into a family narrative, a set of shared experiences and meanings. Interaction, collaboration, and sharing can be direct (a family participating together in an activity or experience) or indirect (the family discussing or doing something together later that builds on an experience a child or adult has had elsewhere).

A Google search of the phrase “family in the 21st Century” reveals an amazing array of responses including links to working families, “Renaissance” dads, stepfamilies, blended families, adopted families, multi-birth families, home-schooling/unschooling families, and so on. The one conclusion that can be drawn is that it is increasingly difficult to define a family. A simple but broad definition is two or more people in a multi-generational group that has an ongoing relationship; they may be biologically related but not necessarily. The general rule is that if a group defines itself as a family, they are one.

Learning can also be defined broadly, including typical notions of remembering facts and concepts, most often expressed in words. However, the definition of learning, particularly for families, also encompasses the development of shared values and beliefs, shifts in attitude, aesthetic understanding, and “learning” in psychomotor ways, such as how to ride a bike or play a group game outside. Learning also includes social/cultural dimensions: learning about how a parent or a child learns, how to think critically and refine one’s learning skills, and how to use the learning resources in a community to the best advantage. This broader definition of learning means that families learn together best when they are naturally engaged in the everyday activities of family life. These activities provide a context for learning about one another as learners and people, for example, how to support and facilitate one another’s interests or the joy of lifelong learning. Also, when trying to understand family learning, the processes of learning are equally important, if not more so, than any products of learning.

Research demonstrates that museums are important settings in which many families spend quality time, learning and building a family narrative as they laugh and learn together. This is an implicit, not an explicit, goal. As a colleague likes to quip, few families wake up on Saturday morning and say, “Hey, let’s go to the aquarium today and learn about teleost fish!” However, interviews with parents in museums demonstrate that they perceive these settings as “good places to take children to learn,” and several studies support the idea that families use museums as socially “mediated” learning environments (Dierking and Falk 1994; Ellenbogen et al. 2007; Falk and Dierking 2013).

Why is it important? By the late 1980s, extensive research provided empirical evidence for what many museum professionals had observed informally for years. Most visitors to most museums, about 60–70 %, were visiting as families (Ellenbogen et al. 2007). Given that families are a major audience, it seems important to support their learning and to use museums as laboratories in which to understand such learning.

Subsequent research also demonstrates that what happens in the home and community is as critical to a person’s success as schooling, suggesting that museums have an opportunity to play an important role in supporting lifelong learning in their communities. After all, less than 1 % of an adult’s life is spent in formal instruction, and even children spend the majority of their waking hours (91 %) outside school.

Research also indicates that visiting museums as a child with one’s family correlates more highly with adult use of museums than visiting with a school group. This further emphasizes the importance of the family audience, both in the here and now, but also as a mechanism for building future audiences. In one study, children indicated that they often prefer to visit museums with their families because they get to look at more things of interest to them personally and can talk to their families about what they are doing and seeing (Jensen 1994). As societies transition into learning societies, with learning opportunities available 24 – 7 – 52 – 80+, museums are positioned well as settings in which families can learn and build identity together.

Research indicates a wide range of factors influencing family learning in museums. Families visit with different expectations, cultural backgrounds, interest levels, belief systems, life experiences, and leisure habits. The visit is viewed by most families as an educational opportunity (with some anticipation of entertainment also – most families do not distinguish between the fun and the learning). The visit is also an important multi-generational social outing (and fortunately we know learning is as much about these social/cultural dimensions as other aspects). These factors influence the visitors' interaction with the exhibition and program material and in turn impact how they respond to the accompanying members of their family. We also know that how they make meaning of these experiences is complex. Some families take time to talk and explore a topic while in the gallery, while others wait until the ride home or 2 weeks later to discuss it over dinner. Also challenging exhibition and program developers working in these settings is that what triggers a family to interact and become engaged has as much to do with why the family is visiting, the understandings and needs they bring to the visit, and the subsequent interactions they will have, as to what exhibitions and programs they may encounter. All complexity aside though, there is evidence that families enjoy engaging and learning in these free-choice, multisensory settings.

Cross-References

- ▶ Learning Science in Informal Contexts
- ▶ Visitor Studies

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Feminism and Science Education

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Keywords

Epistemology; Gender; Identities; Social inequality

Feminism and Science Education

There is no single, coherent recognized "feminism." Rather the feminist movement comprises a range of different schools of thought, organizations, collectives, and loosely formed groups and allegiances, which are often organized around particular foci or theoretical standpoints, which change and develop across time and context. In this sense, it may be more accurate to talk of feminist approaches to science education (or "feminisms" and science education). Examples of different feminist approaches to science education include liberal, radical, socialist, black, and poststructuralist, to name a few. Despite the diversity of theoretical and political lenses and ideologies that feminists bring to science education, feminist approaches do share some common assumptions, namely, the belief that gender inequality is wrong and needs to be challenged, that women are oppressed/dominated by men, and that it is important to advocate for women's rights. In the most recent "second" and "third" waves of Western feminism, feminists have extended these concerns from gender to also include other forms of social inequality, such as social class, "race"/ethnicity, sexuality, disability, and so on.

Within academic fields, such as science education, feminist research is often characterized by a belief in the importance of both theory and practice. Feminists are concerned with not only understanding how and why inequalities are formed, experienced, and perpetuated but also how to bring about change through the practical application of knowledge (referred to as *praxis*).

There is no single feminist methodological approach to science education research, but in line with wider feminist research, the personal is often foregrounded. That is, close attention is given to women's subjective, experiential accounts. In line with the famous feminist slogan "the personal is political," women's and girls' individual stories are seen as shaped by wider structures of power, such that private troubles are revealed as being public issues. Feminist science education research makes use of a wide range of methods, but qualitative methods, such as interviews, ethnography, life histories, and auto/biography, are particularly popular. This is because qualitative methods offer a means for capturing rich data to enable an understanding of the lived reality of girls' and women's lives. While the majority of feminist research has traditionally focused on women (in response to the social and historical dominance by males of knowledge and research), recent years have seen an increased interest in critical feminist approaches to masculinity and education, although this has been relatively slow to spread into feminist science education.

Feminist approaches to science education share a common interest in the operation of power and how practices of power play out within science and science education. Attention has been drawn to the myriad effects, experiences, and implications of power within the practice of science. Feminist science education research has also focused on the intersection of identities and inequalities, for instance, analyzing who can, or cannot, see themselves and be recognized by others as authentic scientific subjects.

Feminist approaches to science education can be loosely classified as falling into three main areas: the epistemology of science, science participation, and science teaching and learning:

1. *Epistemology of science*: Sandra Harding (1986) and Donna Haraway (1985) are two of the key figures associated with the feminist questioning of the masculinist nature of mainstream science. Harding and Haraway were at the forefront of feminist critiques of dominant assumptions about the objective nature of science and developed feminist approaches to the philosophy and practice of science.
2. *Science participation*: Statistics show that girls/women tend to drop out of the science "pipeline" earlier than males and are not equally represented across all areas of science, tending to be underrepresented in the post-compulsory study of the physical sciences and at higher/more senior levels within scientific careers in and beyond academia. Feminist science education research has addressed the reasons for these patterns and inequalities and has documented the experiences of, and issues encountered by, women and girls (from diverse backgrounds) within science, from early years, through formal schooling, and into post-compulsory education, academia, the workplace, and informal science learning environments.
3. *Science teaching and learning*: Feminist approaches to science teaching and learning attempt to show how the culture and practice of science is a socially constructed and located activity. This work attempts to reveal underlying norms, values, and assumptions within science teaching and learning and the ways in which science teaching and learning are socially and historically produced practices, in which particular dominant values, identities, and viewpoints tend to be privileged. Feminist approaches to science teaching and

learning seek to develop and promote new ways of teaching and learning science that are more equitable and inclusive for less powerful groups and communities. This includes promoting more equitable forms of pedagogy, curriculum, and resources.

Feminist Praxis and Science Education: The practice of feminism within science education has not been limited to research and theory. There have been numerous initiatives and intervention programs delivered within and outside schools, which have aimed to improve women's and girls' experiences of teaching, learning, and participating in science. For instance, the Girls into Science and Technology (GIST) project, which ran from 1980 to 1987, was one of the largest and well-known UK action research programs aimed at improving girls' participation in scientific and technological studies at school once these become optional. There are also major national initiatives that continue today; for instance, in the UK, over half of all higher education institutions that are active in STEM (science, technology, engineering, mathematics) subject areas are members of the Athena SWAN Charter, which requires signatories to commit to addressing gender inequalities among their STEM workforce. In the USA, STEM extracurricular programs and initiatives for women and girls abound, and there are some nonprofit organizations that have worked to integrate and coordinate these efforts. For example, the National Girls Collaborative Project is aimed at facilitating collaboration and communication among and between girl-serving STEM organizations and programs. The National Center for Women and Information Technology (NCWIT) is a nonprofit organization with over 450 partners focusing on increasing women's and girls' participation in technology and computing, reforming K-12 computing education, and improving visibility of women in computing. The Women in Engineering ProActive Network (WEPAN) is a nonprofit organization with networks of members on 150 colleges and university campuses, aimed at transforming engineering education to attract, retain, and graduate women engineers.

Cross-References

- ▶ Careers and Gender
- ▶ Epistemology
- ▶ Gender
- ▶ Gender-Inclusive Practices
- ▶ Interests in Science
- ▶ Participation, Gender-Related
- ▶ Values and Western Science Knowledge

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Field-Based Data Collection

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Keywords

Mobile data collection; Probeware

Main Text

Field-based data collection is a science education approach that emulates the practices of scientists to evoke ideas of the nature of science through science praxis. During field-based data collection activities, people use genuine (or sometimes science-like) tools and techniques to collect data in settings outside of the classroom. A common goal of these data collection activities is to shift people's understanding of the nature of science by getting them to "think and act like a scientist" through interaction with the real data they collect and the subsequent analysis of those data (e.g., by graphing or reflecting on patterns within the data). By working directly with data they and their peers collect, learners can also construct new understandings about science.

This approach to science education has become increasingly common in middle- and high-school science classrooms, where the tools and techniques have evolved from paper and pencil to approaches that include high-tech automated sensors, mobile computers, and complex, real-time data visualizations. The advent of probeware – small electronic devices attached to calculators or mobile devices for recording environmental parameters such as pH, temperature, salinity, and dissolved oxygen – has enabled scientists to rapidly capture large amounts of field-based data, changing how scientists collect and share data. These devices and techniques also made powerful contributions to field-based data collection in K-12 science. In the mid- to late-1990s, initiatives seeking to connect every classroom to the Internet enabled students to easily share data collected in the field. For example, helping students learn science through the collection and exchange of field-based data concerning their local climate and environmental surroundings was a purposeful design component of Project Globe.

While the use of field-based data collection ostensibly began as a technique for training soon-to-be scientists (i.e., undergraduate and graduate students majoring in science), it has now moved firmly into the K-12 classroom and even into informal learning contexts, engaging people of all ages and disciplinary backgrounds. Smart phones, with their digital cameras, GPS capabilities, and Internet connectivity, have shifted the landscape of field-based data collection, allowing anyone with such a device to participate. Field-based data collection smartphone "apps" (e.g., iNaturalist and Project Noah) have made data collection easier and more accurate, increasing the opportunities for engagement by students and nonstudents alike. The term citizen science is used to describe a project where nonprofessional scientists engage in data collection activities – often field-based data collection. Although little research exists on the science learning that happens during citizen science projects, the recent explosion of citizen science projects has provided opportunities for students or citizens to collect field-based data related to real scientific studies. Research on the use of mobile, technology-mediated field-based data collection tools inside and outside classrooms is on the rise, and early results indicate the immense potential for science learning and instruction provided by this approach.

Cross-References

- ▶ Citizen Science
- ▶ Handheld Devices
- ▶ History of Science
- ▶ Inquiry as a Teaching Strategy
- ▶ Nature of Science, Assessing of

Five Es

▶ Learning Cycle

Formative Assessment

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Keywords

Assessment; Curriculum; Curriculum-embedded assessment; Feedback; Formative; Formative assessment; Portfolios

Formative assessment refers to assessment that seeks to obtain information about student competence in a particular domain (e.g., science) in order to shape future learning. Typically formative assessment focuses on a specific aspect of student competence (e.g., understanding of the force concept). Teachers use formative assessment prior to beginning a new instructional unit in order to determine students' level of competence and to plan instruction to foster students' progression to the next level of competence. Throughout the instructional unit teachers continuously make use of formative assessment in order to monitor students' progression and adapt instruction where necessary. As such, formative assessment needs to be closely aligned with the curriculum; that is, the formative assessment and the curriculum both need to be based on the same model of student learning. At best, formative assessment is embedded in the curriculum such that learning and assessment become indistinguishable from each other and take place at the same time. When well aligned with the curriculum, formative assessment can provide valuable information not only for the teacher but also for the student. Research has shown that if results from the assessment are fed back to students with respect to which aspects of competence they have mastered and which ones they still have to master, this can be beneficial for students' learning (Hattie 2009). Various sources of evidence may be utilized for formative assessment. In order to monitor student learning, products of student work have been proven most suitable; among them are student worksheets, portfolios, or project documentation. In order to obtain information about students' competence prior to instruction, sources of evidence as they are utilized in summative assessments may be used as well; among them are paper-and-pencil tests based on multiple-choice or open-ended items.

Cross-References

- ▶ Assessment: An Overview
- ▶ Curriculum
- ▶ Summative Assessment
- ▶ Test

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Futures Thinking in Science Education

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Futures thinking is aimed at detecting, inventing, analyzing, and evaluating possible, probable, and preferable futures, the deliberate plurality of the name highlighting the range of future possibilities and notions of alternatives (Slaughter 1996). Variously called futures studies, the futures field, futures research, futuristics, prospective studies, or prognostics, it involves a structured exploration into how society and its physical and cultural environment could be shaped in the future. Increasingly, communities are calling on futures approaches to envisage preferred futures and to compare these with current trends and scenarios of other possible futures. Such thinking is regarded as a valuable approach to dealing with uncertainty, the aim being to understand and evaluate alternatives. In science education, socio-scientific issues (SSIs) offer scope for developing students' futures thinking skills. Such skills are increasingly being recognized in curriculum documentation as one of the goals of general education, and as a consequence, areas of study like "citizenship education" are being developed. In this entry we provide a brief overview of futures thinking, where it could fit in science education and how students' futures thinking might be developed.

Futures thinking assumes that the future world will differ from the present world; that the future is not fixed, but consists of a variety of alternatives; that people are responsible for choosing between alternatives; and that small changes can become major changes over time. Most futures work incorporates:

- Input data (observations, raw data, and empirical evidence that are analyzed and synthesized to produce trends)
- Trends (trajectories, extrapolations, projections, and predictions, based on an analysis of the input data; trends tend to be continuous and monotonic, i.e., relating to one aspect only, such as the increasing proportion of the world's population living in developing countries)
- Drivers (groups of trends that share a common theme, e.g., demographics, globalization, economics, science and technology, equity issues and environmental change)
- Wild cards (high-impact, low-probability events, e.g., natural disasters)
- Outcomes (possibilities and scenarios)

The cumulative effect of even small uncertainties in any of these, means that the range of plausible future worlds is very large.

Hicks (2012) differentiates between futures studies and futures education, the former relating to the academic field of inquiry into futures and the latter referring to the translation of futures concepts into learning experiences that are appropriate for school students. Arguments for including futures thinking in education include fostering students' creative, analytical, and critical thinking skills; empowering individuals and communities to envisage, value, and work towards alternative futures; and developing students' values discourse. In science education, futures thinking has the potential to increase student engagement and their perceptions of the relevance of their science learning. It also has potential to develop students' understanding of key scientific concepts, including the nature of science, and to evaluate the positive and negative potential impacts of science and technology on society.

Having a vision of the future is part of being human. In spite of this, futures education is still in a preemergent state with only a limited number of classroom resources. Many of the activities in these resources are based on futures-specific tools, such as futures wheels, environmental scanning, and cross impact matrices, and the contexts for learning tend to be linked with environmental education and education for sustainability. However, there is incipient interest in embedding futures thinking in science education and *socio-scientific issues* offer an accessible context in which to do so.

Although the potential for explicitly including futures thinking in science education has not yet been extensively studied, some initial investigations have been carried out by David Lloyd and colleagues (e.g., Lloyd 2011). Jones et al. (2012) extended some of these ideas to develop a conceptual framework to engage students in a structured exploration of SSIs. Within this framework, students' attention is focused on identifying and analyzing the existing situation, trends, and drivers. Student understandings of these are then used to explore possible and probable futures in a manner that reduces guesswork while still encouraging creativity. A consideration of the social context within which the changes might take place can be considered at a personal, local, national, and global level. The intention is that this will help move students' decision-making from an egocentric activity to one valuing the welfare of the planet and all its occupants. Futures thinking as part of an SSI-focused science program should therefore provide opportunities – through the building of possible, probable, and preferable futures scenarios – for students to reflect on their own as well as others' values. Taking into account multiple perspectives is important for exposing students to some of the complexities and ambiguities associated with SSIs. Also important is an emphasis on the varied interactions between political, environmental, and equity aspects.

As a relatively un-researched phenomenon, the incorporation of futures thinking in science education offers a rich area for further exploration and investigation. Models are needed for how diverse students across different levels of schooling can be supported to develop their futures thinking skills, and what the impacts might be on students' understandings of science and the nature of science, and on their sense of "place" within our world and their ability to contribute to change. There is therefore a range of issues about which little is currently known: What might be appropriate ways to assess students' futures thinking skills? Does futures thinking enhance students' engagement and achievement in science? What does progression in futures thinking look like in the context of science education? What do appropriate, culturally responsive pedagogies look like? What teacher education and support is needed for teachers to plan and implement science education programs that enhance the development of students' futures thinking skills? Beyond this, Gidley and Hampson (2005), in a comprehensive review of futures education, identify a range of areas requiring further research, including psychological dimensions, diverse ways of knowing, cultural diversity, cultural resources, human/social futures, tackling social systems, and developing integral consciousness. Many of the questions that they identify within these themes could profitably be investigated within the context of science education, for example, how can futures in [science] education foster the coexistence of a tapestry of different cultures on a global scale? How has an increase in the use of computers in [science] classrooms affected the teaching of futures? How can futures in [science] education contribute to a reevaluation of roles and expectations in teacher-teacher/teacher-pupil/pupil-pupil relationships? Does the capability of foresight arise from cultural evolution? Is a "scientific" worldview antithetic to foresight?

All students have images of possible futures, and many of these involve scientific and technological advances. Including these futures images and carefully scaffolding the development of students' futures thinking skills when they explore SSIs offers possibilities that are still largely unexplored.

Cross-References

- ► Socioscientific issues
- ► Values

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Games for Learning

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Keywords

Educational games; Educational technology; Interactive models; Microworlds; Simulation environments

Main Text

Games for learning is a collective term referring to digital games that are purposefully designed to help players learn about a particular topic. A *digital game* is an interactive form of entertainment in which a player's experience is mediated by computer software. Once limited to desktop computers and young boys, digital games are now popular across genders and ages on a large number of electronic devices, such as mobile phones, tablet computers, and specialized gaming consoles (Kafai et al. 2008).

Traditional classroom approaches to science education, with their focus on explicit formalized knowledge structures, seldom connect to or build upon people's tacit intuitive understandings. Well-designed digital games, however, may serve to help learners build informal yet accurate understandings of certain concepts due to their situated and enacted nature (e.g., Gee 2007). However, most commercial games are not designed to help players articulate, connect, and formalize their intuitive understandings or to transfer knowledge to other contexts. So while games for learning inherit many design elements from their leisure counterparts, they must add an extra set of functionalities intended to support the integration of tacit spontaneous concepts (e.g., notions of force or momentum) with instructed concepts, thus preparing players for future learning.

Investigation into the use of games for learning has grown from a small niche area to a major focus of research over the past decade, supported by a corresponding increase in funding for research on educational games and educational technology more generally. In 2006, the Federation of American Scientists issued a widely publicized report stating that games offer a powerful new tool to support education and encouraging an expansion of funded research into the application of complex gaming environments for learning. In 2009, the transformative potential of games for science education was the focus of a special issue of *Science* (Hines et al. 2009).

Games for Learning and Simulations

Research into games for science learning shares some theoretical and methodological roots with research into learning from simulations. Both of these domains stress the importance of the learner as the central participant, active meaning-maker,

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and problem-solver. Similarly, both leverage the power of computers to place the learner in contact with a complex system while providing significant affordances for understanding and controlling that system. Digital games share many design characteristics that support learning in simulations, typically featuring similar interactive models that can be explored through manipulation of certain parameters. However, digital games and simulations differ in that games often engender certain levels of play, engagement, and enjoyment as core design characteristics, whereas simulations for learning do not typically include these elements as core characteristics. Games also incorporate rules and explicit goals for players to achieve or progress, often with accompanying scoring or reward systems that relate to a player's skill and progress. In summary, digital games for science education typically feature (a) digital models that allow users to make choices that affect the states of those models, (b) an overarching set of explicit goals with accompanying systems for measuring progress, and (c) subjective opportunities for play and engagement.

Importance of Design: Leveraging the Medium

More than probably any other feature, it is the specific design of a digital game that determines its efficacy for science learning (as is the case for hands-on labs, books, lectures, and many other learning activities). Simply adding game-like elements to an existing instructional platform does not guarantee that the "gameified" software will be effective. To maximize the potential for success, educators and designers must consider the unique affordances of digital games as a medium in light of the learning goals, learners, teachers, and context. Broadly, these affordances can be grouped into six categories: (1) engagement and affective investment, (2) consequential action and meaningful play, (3) implied scientific stance and perspective, (4) approachable entry, (5) guided trajectory, and (6) just-in-time feedback.

Engagement and Affective Investment. The principal quality of digital games, and what makes them attractive to educators, is their ability to engage students. This engagement, though, goes beyond a narrow sense of "having fun." Games cast players into central roles, as protagonists or "heroes" who must prevail against adversity through wisdom, skill, knowledge, and virtue; and thus, games encourage and facilitate the construction of powerful identities and narratives by providing the ideational resources that such identities cluster around. Players of digital games experience designed trajectories of growth and narratives of increasing power that are fundamentally compelling. Learners can gain a sense of control and self-efficacy in the figured universe of the game. Furthermore, players of video games benefit from the goal-centered nature of play. Players expect conflict and resist frustration, so far as they feel that their goals are achievable and that the game is "playing fair." Continued successes in reaching these goals can help increase the player's investment and sense of authorship over the entire experience. A well-designed game provides ample opportunity for a player's goals and decisions to have a visible, lasting impact on the game experience, so that each individual learner's path is reified as an artifact that is visible and valued.

Consequential Action and Meaningful Play. The most effective games are structured so that the embedded system presents a narrative that progresses in accordance with the actions and decisions of the player. Within this narrative, players experience conflict and uncertainty, and their active interpretation and response to these elements creates instances of meaningful play. The player's actions also have an observable effect on the simulation; this *consequential engagement*, in which choices have an impact on the world, is theorized to be an important driver of conceptual understanding. Consequential engagement arises when learners must consider the consequences of their choices, not only in the proximal sense of analyzing their impact on the simulated world but also in the more reflective sense of examining the context in which those choices were made and their appropriateness under the circumstances (Gresalfi et al. 2009).

Implied Scientific Stance and Perspective. Effective games for learning place the player at the center of the action and orient the player toward desirable perspectives and principled attitudes. In digital games that feature models and systems for science learning, these perspectives can help form disciplinary stances and epistemologies, which are equally as important as the learning of specific content matter. Researchers of games for science learning have observed students of various ages thinking and discoursing like scientists, engaging in scientific inquiry, and exhibiting scientific habits of mind.

Approachable Entry. By their nature, games for learning are exceptionally good at providing challenges that are initially simple but that scale gradually and consistently upward in difficulty and complexity. Games have evolved to include varied forms of scaffolding or support for players (e.g., tutorial levels) that successfully guide players in making initial decisions and prepare them for a more complete immersion within the simulated systems at higher levels. These simulated systems tend to be complex and feature-rich, centered on phenomena and relationships that may be difficult for novices to grapple with. The gentle learning curve designed as an intrinsic aspect of good games, coupled with gradually increasing availability of tools to craft and control the simulated environment, allow learners to demonstrate increased expertise as the game progresses. These demonstrations of expertise are sufficiently rewarding that players will persist with the game even in the face of rising difficulty – not the usual pattern educators may expect when students are involved in an independent learning activity.

Guided Trajectory. Another advantage to the structured nature of games is that tools can be provided, as needed, to guide a player along a predetermined path while still maintaining a personalized and flexible experience. Designers of games for learning can readily guide a player through the material and highlight the salient elements of the game without forcing a player to relinquish agency. Players are not marched lockstep through the material, but neither are they left adrift without any cues to tell them when they are ready to proceed to the next segment. Games can be thought of as designed experiences that help learners develop understanding by guiding them through cycles of performance. These cycles act as both a mechanism to present learners with suitably challenging experiences and also to allow increases in difficulty only when the player is ready for them. Few other learning activities have this property.

Just-in-Time Feedback. Games for learning, as fully interactive media, are able to provide direct, frequent, and useful feedback to the player as the game experience unfolds. This form of feedback can be highly engaging and motivating, and it has been found to be a powerful intermediary for learning (Annetta et al. 2009). The expectation of feedback creates a ready channel for presenting information; players will attend to information presented as hints or help when presented in a just-in-time manner that is consistent with their own goals and the current state of the game. The acquired tendency of players to attend to “hints” or “clues” provides excellent opportunities to present material, such as scientific principles or definitions of terms, which would otherwise be difficult to frame in a way that students would willingly digest.

Current Trends, Challenges, and Future Directions

Games for learning are gaining broad acceptance in the larger educational community as a potentially valuable avenue for delivering science education. This follows a growing agreement that today’s learners demand greater levels of engagement, agency, and personal significance in their learning activities to match the fast-paced, networked, interactive environments where today’s students socialize and have fun.

However, along with this greater acceptance comes a demand for (a) a higher quality of evidence regarding the effect of games for learning on student achievement and (b) a tighter integration of games for learning into existing curricula and classroom practices. The former is most frequently framed as a challenge of assessment, which is driven by the complex behavioral and cognitive phenomena that digital games (and play in general) engender. In addition to observational and quasi-experimental methodologies, researchers can now employ sophisticated statistical tools to provide more nuanced accounts of how students learn through games. Although the path to include games for learning in mainstream educational practice is not clear, progress is being made on several fronts. Teachers are becoming more technology-aware and show greater willingness not only to use games in their classrooms but also to advocate for their use and participate in their design. Likewise, researchers and designers of games for learning are now accounting for the administrative and curricular constraints of classrooms, offering a sound approach to the addressing of state and national content standards, including embedded assessments and support materials. The next generation of games for learning (more effective, more accessible, and better integrated into educational practices) will become a more important feature of science education over the next decade.

Cross-References

- ▶ Handheld Devices
- ▶ Immersive Environments
- ▶ Microworlds
- ▶ Simulation Environments
- ▶ Technology for Informal and Out-of-School Learning of Science
- ▶ Technology for Science Education: History
- ▶ Technology for Science Education: Research

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Gender

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Keywords

Culture; Generations; Sex/gender

Science education researchers have been interested in the differences between boys' and girls' achievement and participation in science education for decades (Calabrese Barton and Brickhouse 2006). This interest is due in part to a concern regarding the inequitable participation of men and women in science careers and in part to a concern that everyone needs to engage competently in science-related issues in their everyday lives.

Across cultures and across generations, there are patterns of behavior and organization in science and science education that differ by sex/gender. These patterns vary by race, class, nationality, and religion and change over time. For example, over the last 20 years there have been very substantial gains in women and girls participation in science and science education. Most measures of science achievement show few differences between men and women. In the science professions, there have been substantial gains in women's participation in many fields. For example, in the USA, more women than men are now entering medical school, most specifically, in pediatrics. Emerging fields such as biomedical engineering attract women in much higher numbers than more traditional fields of engineering. Nevertheless, in many scientific fields (e.g., computer science, economics, physics), women remain persistently underrepresented.

While patterns of participation vary over time and space, in all cultures the patterns are gendered. Sex/gender remains an organizing principle in all societies, and in most cases those practices and attributes associated as masculine are more highly valued than those associated as feminine. The sciences are typically regarded as more masculine than other pursuits. However, within the sciences there is considerable variation in the gender association of a particular scientific subfield.

The masculine association of the sciences is related not only to male/female participation but also to its epistemology (Lemke 2001). Scientific knowledge, like other forms of knowledge, is gendered. Culturally defined values associated with masculinity (objectivity, reason) are also those values most closely aligned with science. While this association of masculine values with science dramatically oversimplifies the practice of science, it is nevertheless a powerful fiction that may serve to exclude those who do not hold to these values.

Thus, researchers have developed pedagogies of science teaching that focus on engaging a wider range of learners. Rather than teaching a single way of being scientific, these pedagogies instead seek to develop students' scientific competencies by building on existing areas of interest and expertise. Rather than treating science as an elite endeavor available to only a few, science education researchers have developed ways of integrating science learning into the everyday lives of learners from all backgrounds and providing ways for science learning to build stronger connections to the learners' home communities (DeWitt, Archer and Osborne 2013).

Researchers have also studied the ways in which the enactment of gender is quite variable depending on race, class, geography, nationality, sexuality, etc (Brickhouse and Potter 2001). While gender is critically important to understanding how individuals understand themselves and present themselves to others, the meaning of gender in these various instantiations is highly diverse. Thus, for researchers studying science learning as the development of identity, gender is a critical element in understanding how and why learners engage in science learning both at home and at school (Fields and Kafai 2013).

Cross-References

- ▶ Achievement Differences and Gender
- ▶ Attitudes, Gender-Related
- ▶ Participation, Gender-Related
- ▶ Sociocultural Perspectives and Gender

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Gender-Inclusive Practices

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Gender-inclusive practices are teaching practices that are explicitly designed to address the learning styles, current and prior experiences, needs, and interests of students of different genders. The concept of gender-inclusive practice has its origin in efforts to address the marginalization of girls from science education. The term "gender-inclusive" originated in the 1980s in Australia with the work of a group of teachers that formed the McClintock Collective (Hildebrand 1989). The use of this term marked a shift in focusing on teaching practice that was "non-sexist" and aimed at eliminating inequity and bias for girls in science to focusing on teaching practice that made central the social construct of gender and its impact on boys' and girls' experiences and learning in science (Harding and Parker 1995).

Reflecting the above history, while one component of gender-inclusive practices is that they aim to minimize bias and sexism in curriculum and teaching, gender-inclusive practices go beyond this to deliberately change and tailor the learning environment, curriculum, assessment, and pedagogy to purposefully include diverse learners across gender lines. While there is some variation in how theorists and researchers describe exactly what this looks like in the classroom, there is a relative consensus that gender-inclusive practices include the following: providing a supportive environment that prioritizes active, collaborative learning; utilizing open-ended assessments that take on a variety of forms and involve diverse contexts; and emphasizing real-life contexts and applications, including the social relevance of science (Brotman and Moore 2008). Furthermore, gender-inclusive practices include challenging how scientific knowledge and practice are defined, since narrow portrayals of the nature and culture of science (such as that science is objective and value-free) can deter diverse learners with regard to gender as well as ethnicity. Finally, in addition to practices at the classroom level, gender-inclusive practices can be considered at the school level as well as at the systemic level (Hildebrand 1989). While gender-inclusive practices involve an explicit attention to issues of gender, they also overlap with practices advocated by general science education reform efforts that aim to articulate what equitable, high quality science education entails (Brotman and Moore 2008).

Cross-References

- ▶ Achievement Differences and Gender
- ▶ Attitudes, Gender-Related
- ▶ Careers and Gender
- ▶ Engagement with Science
- ▶ Gender
- ▶ Interventions, Gender-Related
- ▶ NOS: Cultural Perspectives
- ▶ Participation, Gender-Related
- ▶ Single-Sex Classes in Science
- ▶ Sociocultural Perspectives and Gender

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General Science Teacher Education

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General science teacher education typically aims to prepare teachers for teaching of general science (also known as integrated science or science for simplicity in many countries or regions) at the secondary level. It is different from the preparation of teachers for the specialist science subjects, such as physics, chemistry, and biology, but in some instances overlaps with that for primary science (see, e.g., Abell 2000). It is mostly offered as an undergraduate Bachelor of Education degree by a normal university (or education institute/university) or jointly by the faculties of education and science in a comprehensive university to recruit secondary school leavers, and it lasts for 4–5 years. The aims, objectives, and design of such science teacher preparation programs not only depend on the views and experiences of the science educators in the teacher education institution but are also influenced by stakeholders (education bureaucracies/school systems). For example, education policy and national goals of science education, such as "scientific literacy for all," have led to the mounting of teacher education programs to prepare teachers for teaching junior secondary science or integrated science in China and South Korea, following from similar trends in other countries such as the UK, Canada, and Australia.

Contemporary research and international trends pertaining to developments in science education have had an influence of the curriculum of general science teacher education in many countries with issues such as educational values of history and the Nature of Science (NOS), constructivism, misconceptions/alternative conceptions, metacognition in children's science learning, socio-scientific issues, science-technology-society (STS), scientific inquiry/investigation, and informal or community-based science learning and technology (including educational technology and ICT) in science education being strong examples of research that has shaped the nature of the preparation of general science teachers.

In many countries, an emerging issue influencing general science teacher education has been the recent development of national standards/curricula of science education which outline specific science topics, such as NOS, unifying concepts (e.g., systems, forms, changes, and equilibrium as commonly found in various science topics), skills for scientific inquiry, and the use of ICT as well as scientific attitudes that science teachers need to facilitate their students' development at different stages of learning. As a consequence, guidelines, standards, or position statements on science teacher preparation (see, e.g., National Science Teachers Association 2003) may then be advocated by the community or professional society of science teachers to reflect their views and demands for professional conduct, competencies, and practices in science teaching.

Like any other teacher education program, there is an underlying assumption that general science teachers need to develop in three key domains of knowledge, including (i) subject matter knowledge (SMK) in general science, (ii) pedagogical knowledge (PK), and (iii) pedagogical content knowledge (PCK). The general science SMK consists of a balanced combination of courses in both traditional disciplinary courses in physics, chemistry, and biology and interdisciplinary science and technology courses in environmental science, health science, earth science, biotechnology, and/or telecommunications. Such courses tend to stress the conceptual understanding of the SMK at the undergraduate foundation or intermediate level and de-emphasize the analytical/mathematical manipulations, which are often replaced by computer simulation/modeling. The PK refers to those generic instructional principles, classroom management, curriculum development, learning theories, education policy and educational psychology, etc., which are normally taught by other (nonscience) teacher educators. PCK is perhaps the most complex component of any general science teacher education program. Despite variations in its definition (see, e.g., Gess-Newsome and Lederman 1999), it refers to science teachers' subject-specific pedagogical knowledge, consisting of, but not limited to, (i) orientations or views toward science learning and teaching, (ii) characteristics of science learners, (iii) general science curriculum and its trends of development, (iv) a wide variety of science instructional strategies, and (v) science assessment. There is much research to suggest that PCK is difficult to develop in teacher preparation but that concentration of such knowledge development is key to participants' future professional learning (Loughran et al. 2012).

The teaching of general science in teacher education often emphasizes teaching approaches, such as the thematic approach, integrated learning, issues-based inquiry, and STS approach. It also embraces other commonly used science methods, including problem solving, reasoning by analogy, modeling, scientific visualization, theory-evidence coordination, concept mapping, creativity, technology-enhanced learning (in particular, computer-mediated laboratory work), and higher-order thinking strategies, to name but a few.

Based on the above overview, general science methods courses are typically embedded within learning objectives designed to encourage student-teachers to:

- Be aware of children's cognitive processes, affective domain, and difficulties in science

learning as well as their implications for the teaching and learning of general science.
- Understand various NOS perspectives and their sociocultural linkage, as well as their implications for the teaching and learning of general science.
- Understand the unifying concepts of science as well as their implications for the teaching and learning of general science.
- Understand the nature and requirements of national/local general science curricula and assessment guidelines.
- Select, develop, and apply appropriate pedagogical and assessment strategies to facilitate students' science learning.
- Develop the essential knowledge, skills, and attitudes required for the integration of ICT with science education.
- Develop positive attitudes and professional behaviors toward students, science, and the teaching of general science.

For general science teacher education, there has been rather limited research conducted directly on evaluating the effectiveness of such programs, apart from assessing student-teachers' particular general science subject matter knowledge and understanding of NOS. Rather, student-teachers' science learning is often investigated through the lens of the aforementioned PCK, and this may then be interpreted as an indirect inference of science teacher's competence (see, e.g., Russell and Martin 2007). For example, it had been inferred from some TIMSS findings in Hong Kong that junior secondary pupils taught by teachers with general science teacher training outperformed those taught by physics/chemistry/biology teachers.

Cross-References

- ▶ Biology Teacher Education
- ▶ Chemistry Teacher Education
- ▶ Integrated Science
- ▶ NOS: Cultural Perspectives
- ▶ Pedagogical Content Knowledge in Teacher Education
- ▶ Pedagogical Knowledge
- ▶ Physics Teacher Education
- ▶ Primary/Elementary Science Teacher Education
- ▶ Science, Technology and Society (STS)
- ▶ Secondary Science Teacher Education

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Gifted Education in Science

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Keywords

Acceleration; Domain specificity of giftedness; Enrichment; Special education

Many children show a strong interest in natural phenomena from an early age and demonstrate an outstanding ability to think creatively and in abstract terms. The greater the individual differences in these interests, skills, and ability, the greater is the need for meeting special needs through a high-quality education. In this sense, gifted education is a kind of special education. In the United States, for example, the proportion of children identified as gifted is on average 6 %

nationwide. This is about the same percentage of children that need what is usually brought to mind by the term special education and is therefore not a percentage that can be ignored in ordinary school education activities. Research and practice on gifted education in science could provide a new dimension to the child-centered science education that has spread in the late twentieth century. It is imperative for meeting needs of gifted students in science.

There is no one definition of "gifted," "talented," or "giftedness" that is universally accepted. For convenience, the single word *gifted* is used here to mean *gifted and talented*. To identify a gifted child, a definition of the term is essential. The concept of giftedness is impacted by sociocultural factors. Who is deemed to be gifted can change significantly based on what identification standards are used, along with changes over time, changes in the theories being relied on, and changes in the desired results.

The classical method of identifying a gifted child in many countries has been an IQ test. The IQ test score (e.g., a score of 130 or higher) is still very commonly used as at least a partial basis for identification. In some cases, some upper percentage of a range of scores (e.g., top 10 %) is still used as the standard, based on the notion that a gifted child is someone who performs better than other children of the same age. Researchers and practitioners have come to agree that a more diverse system that incorporates measures other than IQ must be used to identify gifted children.

To identify gifted children, it may be helpful to use general behavioral characteristics of the individual, such as having a large vocabulary, the ability to express themselves well, mental agility, a sense of humor, and concentrate on one thing for a long period of time. However, just because a child can systematically memorize, say, the names and characteristics of hundreds of animated cartoon characters, this does not mean he or she will easily be able to learn and retain the names and properties of the 118 chemical elements or understand the power of the periodic table for organizing these. Similarly, even children who can focus for hours at a time on an activity such as catching insects may not demonstrate any interest in the intricacies of research or the creative arts such as painting or music. It is normal for people to be stronger in some areas and weaker in others. The domain-specific, dynamic nature of science, with its encompassing of a wealth of different fields of study, can accommodate children's varied areas of interest, and for this reason it makes an ideal subject area for children to show their giftedness and in which educators can identify the giftedness. A great deal of attention has recently been paid to science education in research and practice related to domain-specific giftedness.

Taber (2007) discussed gifted education practically from different perspectives in the context of formal secondary school level science education in the United Kingdom. He proposed four clusters of characteristics of what he termed "able science learners" (p. 9): "scientific curiosity," "cognitive abilities," "metacognitive abilities," and "leadership". Sumida (2010) has developed an original behavior checklist that can be used for Japanese primary school children in science classrooms in that non-Western context, including 60 items such as "reports clearly the result of an observation and experiment" and "tries to do things in his/her own way, not according to the instructions given" (p. 2103). As a result of his analysis, three gifted styles in science were identified: "spontaneous style," "expert style," and "solid style."

Among those scientists who have made their mark on history, quite a few are known to have lived with not only outstanding talent and brilliance but also some kind of learning difficulty. Even if a child might be identified as gifted based on multiple criteria, it is possible that the child has special educational needs as well. Unique children who possess both gifts and challenges are referred to as "twice-exceptional" or "dual-exceptional" children. Even when children are identified as gifted, it is inaccurate to view them as perfect children who will demonstrate excellence in every field. Exceptional students will also need support for their unique socio-emotional development.

Gifted Education in Science, Table 1 Two forms and contexts of gifted education program in science

	Formal	Informal
Acceleration	Skipping grade, early entrance, special class, advanced learning in a specific subject, dual enrolment, AP/college credits, differentiation	Dual enrolment, home tutoring, science club
Enrichment	Personal learning, project learning, learning center approach, cooperation with companies or museum/zoo	Saturday/summer/winter science program/camps, science fair/contest, science Olympic, special program in companies or museum/zoo

There are two main forms of gifted education programs. They are "acceleration" and "enrichment." The acceleration is to provide children an opportunity to study the content in the upper grade curriculum and take credits. Skipping grades, special grouping in a specific subject, the forms of advanced placement (AP) courses variously provided in some countries, and dual enrolment are examples of the acceleration. Acceleration does not mean pushing a student beyond their capabilities; it means matching the science curriculum and instruction with the readiness and motivation of the student in order to appropriately extend the student.

Enrichment provides children an opportunity to study interdisciplinary and/or extended content. Forms include personal learning, project learning, center approaches, weekend/vacation programs, and contests. Table 1 summarizes the key characteristics of acceleration and enrichment.

Wai et al. (2010) assessed participation in various educational opportunities such as academic competitions, research apprenticeships, academic clubs, summer programs, and accelerated classes among 1,467 individuals who had been identified as gifted in mathematics at age 13. They found that those who had been involved in more of these educational opportunities (a higher "STEM dose") had, at age 33, a higher rate of notable accomplishments in STEM, such as earning a Ph.D., writing publications, obtaining patents, or securing an academic career.

Several points are proposed for consideration with regard to the development of gifted education in science.

1. There is a need to reevaluate just what young children are potentially capable of doing. At the start of the twenty-first century, various research findings showed that students' scientific competence – even among very young children – exceeded the expectations of the past. When designing formal gifted education, the provision of high-quality education that meets individual needs in early grades is crucial.
2. The second point to be considered is the issue of respect for individuality and diversity in education. In reality, the major issues faced by gifted educators are problems like the students' loss of self-confidence, the pressures related to the perfectionism typical of gifted students, and the underachievement of gifted students in areas outside their interests. An appropriate balance is needed between a focus on acquiring knowledge efficiently and developing skills appropriately within the expected context and on demonstrating independence and collaborative creativity.
3. An appropriate and robust educational model must be developed for gifted students to ensure that their talents are properly cultivated and can blossom fully, and to ensure that these students can actively contribute to society. The development of science curriculum and teaching materials that accommodate the special needs of gifted children and the implementation of related science teaching methods and assessment is relevant to all teaching subjects, school types, and education in general, and can be used in the educational activities of parents and communities as well.
4. The fourth issue to be considered is the need to provide opportunities where all children can demonstrate their giftedness. Support for highly gifted social minorities is an important issue. Opportunities need to be created where all children can develop their giftedness and receive high-quality education.

In conclusion, a model of gifted education must not only cultivate excellent professionals such as scientists and engineers but also must be usable as a model of education that can improve the general literacy of the public. Gifted individuals, even students, should be strongly encouraged to give their maximum effort, just like scientists and athletes. Improving one's own knowledge and raising one's level of thinking and skills is a beautiful process, brings joy and inspiration, and produces educational value that serves as a good model for others. Schools, communities, and families may be able to work collaboratively to clarify their various roles and targets for achieving advancements, diversification, and qualitative improvements in the twenty-first-century science education.

Cross-References

- ▶ Cognitive Acceleration
- ▶ Imagination and Learning Science
- ▶ Interests in Science

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Handheld Devices

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Keywords

Handheld computers; Mobile devices; Mobile learning; Mobile technology; Smartphones; Tablet technology; Ubiquitous learning

Mobile Learning Technology

At present there are three predominant forms of handheld electronic information and communication device: e-book readers, tablet technologies, and smartphones. However, as the range of features offered by each of these devices is extended, the distinctions among them are becoming less clear. This entry reviews the current state of each kind of device and comments on applications for science education.

E-book readers are portable electronic devices designed primarily for the purpose of reading traditional analogue books in digital form, including newspapers and periodicals. This form of digital device is characterized by its comparative low cost, long battery life, and slow screen refresh rates. Many of the low-cost e-book readers incorporate a display technology which reflects light – referred to as "e-ink" – that is designed to emulate the appearance of ink on paper and is reported to be less tiring to read than luminous LCD displays in a variety of light conditions. A feature of this technology, employed by the popular Kindle, Sony Reader, Nook, and Kobo e-book readers, is the ability to display fixed black and white images and text for long periods with minimal use of battery power. Many of these handheld devices now offer touch-sensitive color screens with SD card readers, Wi-Fi, and/or 3G/4G connectivity to mobile telephone service providers to access content.

Tablet technologies are characterized by thin, touch-sensitive color screens with very fast processors and faster screen refresh rates to enhance user interactivity. Tablets are generally more expensive than e-book readers, and the common use of LCD screens offers greater resolution for the display of high-quality images and multimedia in low-light conditions. Many of these devices incorporate global positioning systems (GPS) for map location and multiple cameras for capturing still images or video. These can also be used for teleconferencing or simple multimedia production. Tablet devices are primarily designed to be connected to the internet via Wi-Fi via local area networks provided by educational institutions, libraries, or local Wi-Fi "hotspots" (e.g., cafes, or airports). More expensive tablets also provide 3G/4G connectivity for seamless connection to the Internet via mobile telephone service providers.

Smartphones are presently comparable in cost to larger tablet devices but arguably have

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two key elements that differentiate them from the growing suite of features offered by tablets. Firstly, smartphones by design are intended to be highly portable, which puts limits on their physical size and weight. Originally conceived as a mobile phone with "extended" features, smartphones are now rapidly evolving into smaller tablet devices that offer all of the capabilities found in larger tablets (e.g., GPS, internet connectivity via Wi-Fi, e-mail, and videoconferencing), with the addition of 3G/4G connectivity to mobile phone service providers for voice and SMS text. The continued development of new targeted software applications, referred to as "apps," designed to be downloaded to tablets and smartphones allows users new opportunities to customize the device and thus extend their influence in education, entertainment, and the workplace.

The ubiquitous nature of mobile devices combined with the relative low cost of "apps" means that educators and students are realizing creative and exciting ways to investigate the use of digital pedagogies in science education, e.g., apps that allow students to perform motion analysis, manipulate molecules in 3-D, or view star maps of the night sky. Smartphones and tablets allow students to research information with ease and perform simple data-logging tasks using cameras, video, and sound recording for later data analysis. An exciting development is their use by remote students as a communication tool, enabling them to participate in collaborative science projects or to support face-to-face or virtual presentations to peers. Handheld devices also offer engaging ways for students and teachers to develop and record digital portfolios to showcase student learning and encourage the establishment and growth of science learning communities.

Cross-References

- ▶ Digital Resources for Science Education
- ▶ Field-based Data Collection
- ▶ Multimedia Videos and Podcasting
- ▶ Technology for Science Education: History

Health Education and Science Education

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Keywords

Health; Health literacy; Health promotion; Medicine; Prevention

Health is a paradigmatic *socio-scientific issue* in science education. Given the current high prominence given to socio-scientific issues in many science curricula, there is a very clear and strong case that health issues and health education should be included more intentionally and prominently than these are at present. Several broad arguments that support this claim can be identified in current literature (e.g., Zeyer and Kyburz-Graber 2012). The *grand challenges of the twenty-first century* consistently involve issues directly or indirectly related to health. Incorporating health issues in science education can help in promoting *scientific literacy* and in fostering *critical discourses* on the role of science in society and the role given to science in school contexts. While these arguments have been recognized for decades in *environmental education* and its relationships with science education, the same cannot be said of health education. Yet evidence is particularly strong that health issues awake *interest and motivation* for science in young people. Indeed, in PISA 2006, the ten science topics students found most interesting were all directly or indirectly related to health and medicine (Bybee 2012), and in the Relevance of Science Education (ROSE) study (Schreiner and Sjøberg 2004), girls' interests were predominately focused on health- and medicine-related topics. This crucial link between health and science education is partially recognized in school biology but widely neglected in other school science subjects, for example, school physics, and also in research in science education.

In particular, *biomedicine*, an infinite source of attractive science topics, is far from being sufficiently recognized.

Health literacy is commonly described as the cognitive and social skills which determine the motivation and ability of individuals to gain access to, understand, and use information in ways which promote and maintain good health (WHO 1998, p. 10). It is a key concept for bridging this persisting gap between health promotion, prevention, medicine, and science education and for establishing a new mutual relationship between these fields. Health issues are typically complex, value laden, and epistemologically disputed. They are a salient opportunity for cultural border crossing (Aikenhead 2000) and hence represent an intrinsic challenge to traditional transmissive science education and research of science teaching and learning.

Cross-References

- ▶ Motivation and the Learning of Science
- ▶ Relevance
- ▶ Scientific Literacy
- ▶ Socioscientific Issues

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Heterogeneity of Thinking and Speaking

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Heterogeneity of thinking means that in any culture and in any individual, there exists not one, homogeneous form of thinking, but different types of verbal thinking (Tulviste 1991). This general idea can be also found in other formulations, for example, in the "tool kit" analogy used by Wittgenstein for characterizing his language games. It expresses, also, an acknowledgement that word meanings are essentially polysemous.

The notion of heterogeneity despite genetic hierarchy, discussed by Wertsch (1991), assumes that different forms of thinking can be ranked genetically (in the sense of development or generation), but the latter forms are not assumed to be more powerful. Based on the notion of "spheres of life" mentioned by William James in his description of where common sense, science, and critical philosophy may be adequate and appropriate, and on the "activity-oriented" approach outlined by Tulviste, Wertsch assumes that the development of new forms of activity gives rise to new types of thinking. Nevertheless, since the earlier forms of activity continue to fulfill some role in culture, the old types of thinking employed in these earlier forms are preserved and continue to function well in their appropriate contexts. According to Wertsch (1991), "this position [. . .] can be summarized by saying that although some forms of functioning emerge later than others, they are not inherently better" (p. 97).

Assuming the heterogeneity of thinking implies recognizing the coexistence in the individual of two or more meanings for the same word or concept, which are accessed and used in the appropriate contexts. Science itself is not a homogeneous form of knowing and speaking and can provide multiple ways of seeing the world, which can exist together in the same individual, and be drawn upon in different contexts. For example, the concept of the atom is not restricted to one unique point of view. Chemists deal with the atom as a rigid and indivisible sphere, like the Daltonian atom, in explaining several properties of substances. The structural formulae used by chemists also represent the atoms arranged in molecules in this way. This model is not, however, suitable for explaining several phenomena, including, for example, chemical reactivity, where more sophisticated models, including those derived from quantum mechanics, are used.

A diversity of authors have argued that people can have different ways of seeing and conceptualizing the world. Bachelard, for example, in comment that the concept of mass admitted different meanings, stated that “one concept alone was enough to *disperse* the philosophies and to show that the incompleteness of some philosophies was attributable to the fact that they rested upon one aspect, they illuminated exclusively one facet of the concept” (Bachelard 1968, p. 34). Different ways of knowing and forms of knowledge correspond to the realities of varied social contexts. It can be argued, however, that the concepts and categories available in all the spheres of the world are held in a similar form by a number of individuals, in such a manner that effective communication becomes possible.

These “collective representations,” using the expression of Durkheim, are supra-individual in nature and are imposed upon individual cognition. When Vygotsky pointed to the social dimension of human mental processes, as he did in his general genetic law of cultural development, he was drawing on this position. The fact that those collective constructions are imposed upon individual cognition follows from the development of individual thinking through the construction of an internal plane of functioning by means of cultural tools made available through social interactions. As our social experience is diverse and multifaceted, we do not share only one series of concepts and categories that can be used to signify the world of our experiences. On the contrary, we have at our disposal a diversity of stabilized meanings in different social languages, the weight each of them in our personal way of thinking depending on the extent to which we had opportunities to fruitfully use them throughout our development, in order to face challenges posed by our experiences.

For certain concepts the heterogeneity of thinking and speaking is so overwhelming that each community has its own conceptual ways of dealing with a particular concept in the contextual situations that demand its use. This is the case of the concepts of heat and temperature. Consider two communities for whom these concepts are very important: firefighters and air-conditioning technicians. While for the first community heat is heavily associated with hot things, for the second there are two kinds of “heat,” operating in different contexts: the hot “heat” and the cold “heat.” When installing an air conditioner in a room, members of the second community talk about “avoiding the cold escaping from the room through isolating it.” Thus, these two communities each have a theory for heat that is quite different, and both are quite different from the scientific theory, yet each works very well in the context in which it was developed and specifically applied.

A way of modeling this heterogeneity of verbal thinking is through the theory of conceptual profiles (Mortimer and El-Hani 2014). Conceptual profiles can be seen as models of the heterogeneity of modes of thinking and speaking available for people with a given cultural background to use in a variety of contexts or domains. Modes of thinking are treated here as stable manners of conceptualizing a given kind of experience, by ascribing to it a socially constructed meaning attributed to a certain concept. In our approach, each mode of thinking is modeled as a zone in a conceptual profile, stabilized by ontological, epistemological, and axiological commitments underlying meaning making about a concept. Thus, we are not dealing only with an individual’s conceptual thinking, but with how it comes to be constrained by a set of socially constructed commitments, which in turn grounds the ascription of particular meanings to a concept.

Conceptual profiles are built for a given concept and are constituted by several zones, each representing a particular mode of thinking about that concept, related to a particular way of speaking. Each individual has his or her own individual conceptual profile. It is important to notice, however, that, according to the conceptual profile theory, it is only the relative importance (or "weight") of the zones that varies from person to person, while the zones or modes of thinking themselves are shared by individuals in a given sociocultural background, as maintained by sociocultural approaches to human action. Those differences in relative importance depend on the individual's experience, which offered and offers more or less opportunities for applying each zone in its appropriate contexts. For example, consider the concept of "mass." The empiricist notion of mass, as something that can be determined with a scale, is likely to have a greater importance in the profile of a chemist who works daily in a chemical laboratory weighing samples than a rational notion of mass as the ratio of resultant force and acceleration. The opposite holds true for a physics teacher who teaches Newton's laws every year to several classes. In this sense, each individual has a different conceptual profile for each concept, with different weights in each zone, depending on their everyday school and work experiences.

For example, in a conceptual profile built for the scientific concept of "heat," we find a zone corresponding to the scientific way of thinking about heat as a process of energy transfer between systems at different temperatures and modes of thinking related to the everyday concept of heat which assumes heat as being substantive in nature and proportional to temperature (so that we can speak about "cold heat" and "hot heat"). In the science classroom, students should learn the scientific concept. This amounts to an enrichment of the conceptual profile of heat. In everyday life, they will find, however, discursive contexts that reinforce the idea that heat is a substance and is proportional to temperature. To put it differently, the pragmatic value of everyday language will preserve meanings that are at odds with the scientific view. For instance, in a shop a student will naturally ask for a "warm woolen coat." This mode of speaking is far more appropriate and powerful than the scientific discourse in that context, and, due to the inextricable relationship between thought and language, it is likely to bring with it a corresponding mode of thinking. After all, communication with the salesperson will only be more difficult if the student asked for "a coat made from a good thermal insulator, which prevents the body from exchanging heat with the environment."

This example leads to two important conclusions: (1) scientific modes of thinking and speaking are not more powerful in all contexts of experience, but just in some of them – thus, science education cannot take as a goal the replacement of everyday language by scientific language; (2) the usage of particular language has consequences, since it is closely and importantly related to modes of thinking and plays a central role in how we deal with different problems in our everyday lives. Hence, one should accept the fact that each of everyday language and scientific language tend to be used in different contexts, where each of them shows pragmatic value. One is not really recognizing what is at stake if one says that when the student asked for a "warm woolen coat," she was just using a manner of speaking. All that is consequential in relation to this event concerns the fact that she used a specific mode of speaking!

The Bakhtinian notions of speech genres and social languages can help us find ways to relate different zones of a conceptual profile with different ways of speaking. Bakhtin claims that a national language is not unique, but composed of several different social languages, which "are specific points of view on the world, forms for conceptualizing the world in words, specific world views, each characterized by its own objects, meanings and values. As such they all may be juxtaposed to one another, mutually supplement one another and co-exist in the consciousness of real people" (Bakhtin 1981, p. 292).

In addition, we should consider that to become aware of a multiplicity of meanings and contexts involves, in our terms, the dialogue between new and old zones in a conceptual profile. Any true understanding, or meaning making, is dialogic in nature because we lay down a set of our own answering words for each word of an utterance we are in the process of understanding.

Another interesting question to address is which sequences of communicative approaches (Mortimer and Scott 2003) would be more productive in a teaching/learning context while engaging in a dialogic relationship with students committed to different worldviews and ways of knowing, provided that neither students nor teachers can forget that the main goal is to understand scientific ideas.

Dialogic approaches in the beginning of a teaching sequence offer the opportunity for students to express their views and then later to see how these views relate to a given scientific perspective. In addition, dialogic engagement is potentially motivating of students, drawing them into the problem at hand and legitimizing their expression of whatever ways of talking and thinking they possess. At the same time, dialogic approaches should not be restricted to the initial exploration of students' conceptions. It is important that students have also the opportunity to explore newly learned scientific ideas for themselves through talk and other actions.

Nevertheless, dialogic approaches alone do not ensure meaningful learning. Normal science is played through authoritative discourse, which offers a structured view of the world. It is not possible to be introduced to the tools of scientific reasoning without guidance and assistance. The authority of scientific arguments helps to develop a high degree of intersubjectivity between different people sharing the same scientific paradigm. Thus, if meaningful learning involves making connections between ways of thinking and talking, science teaching should allow for a progressive shifting between authoritative and dialogic communicative approaches, with each giving rise to the other. Thus in a teaching sequence, it is possible to find moments when the teacher encourages dialogic discourse to make students' everyday views available, so as to help students become aware of them. The approach can be shifted to an authoritative one when she aims at introducing the scientific point of view. Then she prompts dialogic discourse as she encourages students to explore and apply the scientific view. Thus, the shifts in communicative approach continue throughout the teaching sequence.

Assuming the heterogeneity of language, meaning, and thinking and the dialogic nature of understanding and learning as theoretical principles that support conceptual profiles, we are in a position to define the basic tasks that should be carried out if we wish to understand how people learn scientific concepts and how these concepts can be taught in terms of conceptual profiles:

1. Determine the zones that constitute the conceptual profile for a number of central concepts.
2. Characterize individual conceptual profiles by investigating how these zones are used in different contexts by individuals belonging to certain groups.
3. Investigate the interplay between different ways of thinking and modes of speaking in the meaning making process in science classrooms.

The conceptual profile notion helps answer the question of what kind of learning should be expected in culturally sensitive science teaching. It preserves the idea that to develop a conceptual understanding in science, it is necessary to establish relationships between scientific and everyday meanings for the same words. But this relationship is not one of subsuming all other forms of knowledge into science; rather it is one of dialoguing between different forms of knowledge in order to clearly distinguish among them and among the contexts in which they can be better applied. In this sense, meanings other than the scientific ones that a word can acquire are not treated as "inferior," but as culturally adequate for the different spheres of life in which we act and talk. This does not mean that one should necessarily avoid being critical about common sense and other culturally based views, but rather that one is entitled to restrict the validity of these criticisms to the domain in which science is valid. In critiquing, for instance, a commonsense view that heat is proportional to temperature and opposed to another form of heat, "cold," a teacher should insist that this latter view is different from the scientific one while also accepting that it is far more convenient to speak about "cold" and "hot" things in everyday life as these have deep cultural roots, are part of our language, and allow for communication in most everyday situations and activities.

Nevertheless, to deal with other everyday life situations, the scientific view of heat as a process of energy transfer is far more convenient than the commonsense view of heat and cold as properties of materials. Consider, for example, a case in which one has to decide which type of container is better to preserve the low temperature of a drink in a warm day, one made of aluminum or one made of glass. The commonsense view would lead us to choose the aluminum, since it is "cold." The scientific view, instead, helps us understand that this coldness is due to the transfer of heat from the aluminum to the liquid, thus making the drink warmer. Since aluminum is a better thermal conductor than glass, the drink will get warmer more quickly in the aluminum than in the glass.

It is in this sense that we claim that the heterogeneity of thinking and speaking helps us comprehend how a student can come to apply a scientific idea she understands in some but not all contexts of her daily life. In the first case, to talk about warm clothes, the commonsense view is far more convenient. In the second, to decide in which type of glass to drink a cold drink in a warm day, the scientific view is much more appropriate. If we help a student to become aware of her conceptual profile of heat and temperature after learning the scientific view, she can comprehend in which contexts of daily life she can apply this scientific view she came to understand.

Finally, it is most important to note that by proposing a theory that holds multiplicity of meanings and dialogue as basic principles, we seek to position the science learner in a place coherent with her pluralist condition of belonging to different communities and dealing with different points of view. This pluralist condition constitutes the rule and not the exception in the lives of most students.

In presenting heterogeneity of thinking and speaking as a cornerstone to learning science, we intend to restate the centrality of conceptual learning for the endeavor of teaching science, while recognizing, at the same time, the importance of culture, language, and context in this process. Even if science curricula today tend to be built around thematic and contextual issues, the essential intent of adopting such approaches includes the learning of scientific concepts, something that is still at the core of the problematic nature of science teaching and learning.

Cross-References

- ▶ Action and Science Learning
- ▶ Activity Theory and Science Learning
- ▶ Alternative Conceptions/Frameworks/Misconceptions
- ▶ Borders/Border Crossing
- ▶ Communities of Practice
- ▶ Conceptual Change in Learning
- ▶ Cultural Influences on Science Education
- ▶ Dialogic Teaching and Learning
- ▶ Discourse in Science Learning
- ▶ Language and Learning Science
- ▶ Meaningful Learning
- ▶ Scientific Language
- ▶ Socio-Cultural Perspectives on Learning Science
- ▶ Teaching and Sociocultural Perspectives

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Hidden Curriculum

- ▶ Companion Meanings
- ▶ Curriculum

High Stakes Testing

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Keywords

Standardized achievement tests

"High stakes tests" are so labeled because they carry serious consequences for the students and/or educators. They normally take the form of standardized achievement tests and are common tests across a nation, state, or city. The results of the tests impact on students in terms of whether they get a special diploma or certificate for gaining entrance to a higher level of education. There is impact on schools or teachers or educators including financial rewards, funding level provisions, public perceptions, social status, or even sanctions.

As the consequences are serious, parents, students, educators, and the public in general have concerns about these tests, including validity issues and unintended negative consequences. Some researchers are of the view that it will require further studies to establish the positive impact of these tests. They maintain that there is a lack of evidence to show that testing improves student learning or instruction. There are financial implications for the design and administration of the tests. Some educators are concerned about teaching to the test, as less emphasis may be placed on concepts or content which are not tested.

Despite the serious consequences, there are researchers who advocate for the positive impact of high stakes testing. They maintain that students become more motivated or work harder and parents become more involved. There are suggestions that high stakes testing provides fair judgement for progression to higher education. Good scores further motivate student learning, while teachers provide better instruction to students and are motivated to figure out ways to improve student learning outcomes.

There are suggestions to provide alternatives to the large-scale testing approach, e.g., adoption of school-based assessment. These practices have led to discussion and research on teacher judgement. Furthermore, there is research which looks into the impact of high stakes testing on ethnic minorities and ELLs.

Cross-References

- ▶ Alignment
- ▶ Assessment: An Overview
- ▶ Assessment: PISA Science
- ▶ Assessment to Inform Science Education

History of Science

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Keywords

Case studies; History; Interdisciplinarity; Kuhn; Nature of science; Philosophy of science

History of science is one of the reference disciplines in science education research and practice. Science education and the history of science have a long record of interactions, based on the role that history has consistently played in the narratives of science and its teaching. But, in addition, they have lived convergent developments in their making as modern academic disciplines from the

1960s to the present. A good illustration of this special relationship is the large impact that, in the last half century, Thomas S. Kuhn's *The Structure of Scientific Revolutions* has had on both fields. But the lives of history of science within science education are not restricted by the Kuhnian framework. The integration of history of science in science education has been shaped by a wide range of approaches and intellectual traditions. The development of history of science and science education as independent academic disciplines has also contributed to their estrangement, in spite of preserving a fertile common ground for cooperative assessments of the nature of science and its practice.

The history of science has been used as a tool in science education with the aim of providing an accurate view of how science works, a better understanding of scientific concepts and ways of knowing, and a contextual account of the place of science in human culture and society. It contributes to enhance motivation among students with regard to subjects often considered difficult, to provide a sweeping picture of science as culture, and to encourage informed participation in science and technology debates in the context of active citizenship. History of science is able to provide teachers and students with a wider and deeper understanding of science and the natural world. In addition to these large aims, history of science is a strategic resource for the production of pedagogical tools aimed at developing specific educational goals. It has intervened, for instance, in the study of conceptual change, the improvement of scientific literacy, and the dissection of the process of scientific discovery, theory building and experimental evidence uses. Pedagogical actions have made use of elements such as the replication of historical experiments, the use of classic science texts, the analysis of science rhetoric and syntax, and the building of pedagogical narratives by means of biography and key conceptual and experimental developments in historical perspective.

Putting history of science to work in science education is an acknowledgement of the fact that "history" and "science" are not mutually exclusive at all. Past events in science can be productively used to reflect on current problems. Whether leading to standard knowledge still in use, or to knowledge discarded in contemporary views, the past obviously offers the benefit of hindsight. Furthermore, the writing of science's past is supported by a mature discipline, history of science, characterized by a healthy pluralism and constructive criticism, thus able to offer penetrating insights on the making of science.

By engaging with history of science, students can reenact science in the making, according to past experiences, to confront analogous practical and intellectual problems and to deal with comparable debates to those prompted by the original events. Students can gain thus a deeper understanding of the nature and practice of science and in parallel develop their own knowledge and competence. Moreover, research in science education has proved that, in spite of their obsolescence (by current science standards), the conceptual frameworks of past science are useful to reflect on the preconceptions held by current students and the pedagogical processes required to further the learning of new knowledge through conceptual change. Thus, a connection is established between the nature and acquisition of scientific knowledge, past and present, which is of great methodological use in the creation of pedagogical knowledge.

The creation and implementation of this knowledge in the classroom requires a number of techniques of intellectual abstraction and communication which involve turning to several bodies of disciplinary knowledge, including not only the history of science but also pedagogy, psychology, philosophy of science, sociology of scientific knowledge, and science and technology studies. Indeed, the use of history in science education comes usually in the form of integrated history and philosophy of science and case studies. This approach is a reflection of the early development of science education research and history of science as modern academic disciplines in the 1960s. But, in addition, it is a testimony to the pluralism of science education as a research subject.

Like philosophers of science, in the last half century, science education scholars have made a good use of history of science to develop case studies, with the aim of gaining a better understanding of the nature of science and implementing it in the classroom. However, as for historically minded philosophy of science, the use of history of science in science education is not a simple matter of applying knowledge coming from a different field. Instead, it requires a cooperative process of appropriation and integration which involves most reference disciplines within science education.

Aligning history of science with science education requires focusing on specific aspects of science in historical perspective which are potentially useful to confront special problems identified by educationists in contemporary teaching and learning of science. Furthermore, it requires operating under a solid and explicit educational theory, including a coherent integration of pedagogical, philosophical, and psychological elements, among others. The construction of such theory and the integration of history of science within it is obviously a complex endeavor, which often involves tensions between the different disciplinary frameworks involved. The successful resolution of these tensions requires transformation as a new field of knowledge is formed.

The difficulties of such enterprise have partly hindered a larger success of history of science within science education. While history of science occupies a traditional place within science teaching, as a way of humanizing science and illustrating its cultural status, its use as a powerful tool in science education research and practice is less common. Further obstacles arise from the difficulty of providing teachers and educationists with adequate training in an additional discipline, the complexity acquired by history of science as it has developed into a well-established discipline, and the increasing distance that separates historians of science and science education scholars as the two communities have built their own academic niches.

Nonetheless, there is an important community of scholars who have developed during the last half century major work which successfully integrates history of science in science education, and there are important scholarly frameworks for the development of team work aligning science education scholars and historians of science in the production of educational research and pedagogical materials.

Early examples of such initiatives include the *History of Science Cases for High Schools* developed in the 1960s by Leonard E. Klopfer and his collaborators on the model of James B. Conant's *Harvard Case Histories in Experimental Science*; the *Harvard Project Physics* ran between the 1960s and early 1970s by Gerald Holton, F. James Rutherford, and Fletcher G. Watson; and Stephen G. Brush's initiatives in the 1970s and 1980s, leading to contributions such as his *Resources for the History of Physics* and a revised edition of Holton's *Introduction to Concepts and Theories in Physical Science*. Since then, a large number of educational projects have incorporated history of science as a driving agent in their design. It would be impossible to cite all of them, but representative examples are the *Minnesota Case Study Collection* directed by Douglas Allchin; *Mindworks: Making Scientific Concepts Come Alive*, led by Barbara Becker; the *Pavia Physics Project*, coordinated by Favio Bevilacqua; *Project 2061* of the American Association for the Advancement of Science; and the European History and Philosophy in Science Teaching (HIPTS) project. The integration of history and philosophy of science in science education is the driving force behind the International History, Philosophy and Science Teaching Group, established in the late 1980s, and its flagship journal *Science & Education*.

The status of history of science in science education research and practice rests on a solid foundation. However, its consolidation will depend, first, on the production of further studies demonstrating that history of science contributes to significant improvement and increased efficiency in science education and, second, on the willingness of historians of science and science education scholars to cooperate and to fight against the effects of academic fragmentation, caused by disciplinary specialization. This effort could involve, on the one hand, the establishment of more ambitious and updated training schemes in history of science within science education programs, taking into account the major changes that have shaped this discipline in the last decade. On the other hand, it would require a greater acknowledgement by historians of science of the central role that educational research can play in the intellectual and academic development of their own subject and the availability of a large body of expertise in this field in their neighboring faculty of education. Misconceptions on the nature of education and on the nature of history are still frequent on both sides of the divide, but they could be fruitfully overcome with the strengthening and expansion of interdisciplinary programs of intellectual and educational cooperation.

Cross-References

- ▶ Biology, Philosophy of
- ▶ Chemistry, Philosophy of
- ▶ Context of Discovery and Context of Justification
- ▶ Earth Science, Philosophy of
- ▶ Empiricism

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History of Science in the Curriculum

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In the middle of the nineteenth century, the Duke of Argyll, in his presidential address to the British Association for the Advancement of Science, stated that "what we want in the teaching of the young, is, not so much mere results, as the *methods* and above all, the *history* of science." The Duke's exhortation has been more ignored than followed, but there has been a minority tradition in the US, UK, and European science education that has attempted to bring history into science curricula and classrooms. This minority tradition has been energized over the past decade by widespread inclusion of "Nature of Science" goals into national and state curriculum documents and science education standards; the argument of many is that the nature of science cannot be understood apart from its history.

At different times and places, there have been appeals to the following seven reasons for including a historical component in science programs (Matthews 1994):

1. History promotes the better comprehension of scientific concepts and methods.
2. Historical approaches connect the development of individual thinking with the development of scientific ideas.
3. History of science is intrinsically worthwhile. Important episodes in the history of science and culture – the Scientific Revolution, Darwinism, discovery of penicillin, and so on – should be familiar to all students.
4. History is necessary to understand the nature of science.
5. History counteracts the scientism and dogmatism that are commonly found in science texts and classes.
6. History, by examining the life and times of individual scientists, humanizes the subject matter of science, making it less abstract and more engaging for students.

7. History allows connections to be made within topics and disciplines of science, as well as with other academic disciplines; history displays the integrative and interdependent nature of human achievements.

The subject matter, or "disciplinary," arguments for history were well stated by Ernst Mayr in the opening pages of his *The Growth of Biological Thought*:

> I feel that the study of the history of a field is the best way of acquiring an understanding of its concepts. Only by going over the hard way by which these concepts were worked out – by learning all the earlier wrong assumptions that had to be refuted one by one, in other words by learning all past mistakes – can one hope to acquire a really thorough and sound understanding. In science one learns not only by one's own mistakes but by the history of the mistakes of others. (Mayr 1982, p. 20)

"Integrationist" arguments have long been the backbone of liberal approaches to the teaching of science such as those proposed by Percy Nunn, James Conant, Gerald Holton, and others. They were the core of the Harvard Committee Report, *General Education in a Free Society* (Conant 1945), and were prominent in the Harvard Project Physics program. Science has developed in conjunction with mathematics, philosophy, technology, theology, and commerce. In turn it has affected each of these fields, as well as literature and culture more generally. History allows science programs to reveal to students something of this rich tapestry and engender their appreciation of the interconnectedness of human intellectual and practical endeavors. James Conant's two-volume *Harvard Case Histories in Experimental Science* (Conant 1957) embodied these ideals and became a popular university textbook.

The success of Conant's Harvard Case Studies in college courses, and the example of Joseph Schwab's historical text-based science course at the University of Chicago (Schwab 1950), prompted Leo Klopfer to emulate the approach in the teaching of secondary science. He produced a course of *History of Science Cases for Schools* (Klopfer 1969). Each of eight cases was presented in a separate booklet containing the historical narrative, quotations from scientists' original papers, pertinent student experiments and exercises, marginal notes and questions, and space for students to write answers to questions. Teachers' guides and supplementary material were also produced.

In the USA these historically informed courses were marginalized after the 1957 Sputnik shock and the subsequent avalanche of National Science Foundation funded "catch-up-with-the-Russians" curricula – PSSC, BSCC, ESCP, SAPA, and so on. Two prominent exceptions were the Harvard Project Physics course and the Yellow Version of the BSCS *High School Biology* for which Joseph Schwab wrote the Teacher's Handbook.

In the 1980s all of the opening seven arguments for history in school science were made in influential American Association for Advancement of Science (AAAS) publications and working groups that arose from its *Project 2061* study chaired by James Rutherford who was originally involved with Conant at Harvard, then with the Harvard Project Physics course. The project's *Science for All Americans* (Rutherford and Ahlgren 1990) contained one chapter recognizing the importance of philosophy in science education and another arguing for a historical treatment of curriculum topics. The AAAS position was elaborated a year later in *The Liberal Art of Science* where it was said that:

> The teaching of science must explore the interplay between science and the intellectual and cultural traditions in which it is firmly embedded. Science has a history that can demonstrate the relationship between science and the wider world of ideas and can illuminate contemporary issues. (AAAS 1990, p. xiv)

These policy recommendations were embodied in the US Science Education Standards published by the National Research Council in 1996 (NRC 1996), where it was stated that:

> The standards for the history and nature of science recommend the use of history in school science programs to clarify different aspects of scientific inquiry, the human aspects of science, and the role that science has played in the development of various cultures. (NRC 1996, p.107)

In Britain there has also been a long tradition following the Duke of Argyll's exhortation to bring history into science programs. In the interwar years the major figures were Frederick W. Westaway and E.J. Holmyard, both of whom were historians of science, textbook writers, and deeply involved with teacher education. History had a checkered career through the many modifications of the English National Curriculum. Great prominence was given to it in Attainment Target 17 of the first 1988 draft where it was stated:

> Pupils should develop their knowledge and understanding of the ways in which scientific ideas change through time and how the nature of these ideas and the uses to which they are put are affected by the social, moral, spiritual and cultural contexts in which they are developed. (NCC 1988, p. 113.

But as in the USA, these lofty ideals simply did not transfer into classroom practice or examination questions, and progressively the historical and philosophical components of the National Curriculum were whittled away, and with the publication of the Dearing Report (1993), they just about disappeared off the English curricular landscape. One encouraging development has been the introduction in 2007 of the *Perspectives on Science* course for final year students. This curriculum, texts and examination, is explicitly concerned with "The History, Philosophy and Ethics of Science" (Swinbank and Taylor, 2007).

The professional purpose of science education is to introduce students into the conceptual and procedural realms of science. It has been argued that history of science facilitates this introduction. But science education also has a wider purpose which is to help students learn *about* science – its changing methods, its forms of organization, its methods of proof, its interrelationships with the rest of culture, and so forth. Many, as above, have argued that this requires contextual and historical approaches to science teaching.

The integrative function of history is perhaps its fundamental value to science education. History allows seemingly unrelated topics within a science discipline to be connected to each other – Einstein's analysis of Brownian motion to confirm the atomic hypothesis, with Brown's attempts to prove vitalism in biology, and maybe even Brown's botanical work in the early exploration of Australia. History also connects topics across the scientific disciplines – unraveling of the DNA code connected geology, crystallography, chemistry, and molecular biology. Historical study shows the interconnections between different realms of knowledge – mathematics, philosophy, theology, and physics all had parts to play in the development of, for instance, Newtonian mechanics and the conservation laws. Finally, history allows some appreciation of the interconnections of realms of academic knowledge with economic, societal, and cultural factors. Darwinian evolutionary theory was affected by, and in turn affected, religion, literature, political theory, and educational practice. Historical presentation can weave all sorts of seemingly separate topics into strands within disciplines and connect the strands into an intellectual tapestry (Holton 2003). Students having some such picture is a central concern of liberal education (Dressel 1979).

Cross-References

- ▶ Curriculum Movements in Science Education
- ▶ History of Science
- ▶ History of Science, Assessing Knowledge of
- ▶ NOS: Cultural Perspectives

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History of Science, Assessing Knowledge of

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History of Science in Precollege Science Education

History of science (HOS) has long been advocated as a significant curriculum and an instructional emphasis in science education (Conant 1948). Indeed, in the United States, HOS has been systematically integrated into precollege science textbooks and instructional materials since the 1950s, albeit under different modalities. Examples of such integration and contrasting modalities include the *History of Science Cases for High Schools* (HOSC) (Cooley and Klopfer 1963) and *Project Physics Course* (PPC) (Rutherford et al. 1970). A systematic curricular emphasis on HOS in precollege science education continued into the 1990s. For instance, the *Benchmarks for Science Literacy* and *National Science Education Standards* included specific, grade-band HOS learning outcomes under "historical perspectives" and "HOS" standards, respectively.

The *National Science Education Standards* (NRC 1996) HOS standards for grades 9–12 include:

- "In history, diverse cultures have contributed scientific knowledge and technologic inventions. The science that aided the development of modern industrialized societies began to be developed in Europe several hundred years ago. Western, as well as non-Western cultures (e.g., Egyptian, Chinese, Hindu, and Arabic), have developed scientific ideas and solved human problems through technology.
- Usually, changes in science occur as small modifications in extant knowledge. The daily work of science and engineering results in incremental advances in our understanding of the world and our ability to meet human needs and aspirations. Much can be learned about the internal workings of science and the nature of science from study of individual scientists, in their daily work, and their efforts to advance scientific knowledge in their area of study.
- Occasionally, there are advances in science and technology that have important and long-lasting effects on science and society." (pp. 201–204)

Previous to the *National Science Education Standards*, the National Science Teachers Association, as part of its Scope, Sequence, and Coordination of Secondary School Science, (NSTA 1995) listed the following ideas related to HOS:

- In history, diverse cultures have contributed scientific knowledge and technologic inventions. The science that aided the development of modern industrialized societies began to be developed in Europe several hundred years ago. Western, as well as non-Western cultures (e.g., Egyptian, Chinese, Hindu, and Arabic), have developed scientific ideas and solved human problems through technology.

- Usually, changes in science occur as small modifications in extant knowledge. The daily work of science and engineering results in incremental advances in our understanding of the world and our ability to meet human needs and aspirations. Much can be learned about the internal workings of science and the nature of science from study of individual scientists, in their daily work, and their efforts to advance scientific knowledge in their area of study.
- Occasionally, there are advances in science and technology that have important and long-lasting effects on science and society. The following we singled out as important for students to study: Copernican revolution, Newtonian mechanics, relativity, geologic time scale, plate tectonics, atomic theory, nuclear physics, biological evolution, germ theory, industrial revolution, molecular biology, information and communication, quantum theory, technology, galactic universe, and medical and health technology (p. 140).

These outcomes can be summarized into three main reasons for including HOS in curricula and instruction, and they all are closely related to the more well-defined aspects of nature of scientific knowledge (e.g., tentativeness, creativity, subjectivity, and cultural embeddedness) (see Measurement of NOS and Assessment of NOS entries). The first is that HOS provides concrete examples about how the scientific enterprise operates. In this sense, HOS serves to contextualize and facilitate teaching about nature of science and scientific inquiry. For instance, enabling students to develop robust understandings of the stable but tentative nature of scientific knowledge would be difficult without recourse to extended historical episodes of the development of such knowledge. Similarly, students are better positioned to develop a sense of the role of paradigms and theories in the development of claims to scientific knowledge because following the stories and understanding the cultural and theoretical convictions of the scientists through the years can help provide a sense of how, why, and when scientific knowledge was accepted or rejected.

The second reason is that HOS illustrates the human and social aspects of the scientific enterprise and its interface with society. For example, under this dimension, the aforementioned recommendations from the NSTA and NRC emphasized the importance of coming to understand that individuals and groups of collaborators from many cultures and nations across the globe have carried out science. They may do so in culturally distinct ways, and examples from HOS can exemplify the cultural embeddedness of science as well as its collaborative nature.

The third reason stems from the fact that many episodes in the development of science are inextricably intertwined with the cultural heritage of humanity. Specifically, developments in scientific understandings of the natural world have been chiefly responsible for or, at least, closely associated with major shifts in how humans have come to understand their own “place” in the universe and their relationship to each other and their surroundings. Examples of these episodes include the Copernican revolution, which displaced humans from the center of the universe; Newtonian mechanics, which by showing that earthly and heavenly movements are governed by the same set of laws helped erase the pronounced separation of the terrestrial and celestial spheres that had dominated natural philosophy since antiquity; Lyell’s investigations that seeded our currently taken-for-granted conception of deep, geologic timescale associated with the development of the earth’s geologic features; and Darwin’s evolutionary theory, which shattered long-held beliefs about the nature and underlying causes of the diversity and relatedness of life on earth and advanced the mechanism of natural selection, which continues to generate significant discourse and discord at the interface of science, religion, and culture. Other major advances recommended by NSTA include plate tectonics, atomic theory, nuclear physics, germ theory, industrial revolution, molecular biology, information and communication, quantum theory, technology, galactic universe, and medical and health technology.

Assessments and HOS

Interestingly enough, despite the focus on HOS and the affordances for student science learning, this domain has rarely been the focus of assessment as an instructional outcome in and of itself. This state of affairs largely stems from the treatment of HOS in curricula and instructional materials. Indeed, the most prevalent modality for inclusion of HOS in science textbooks amounts to vignettes – both shorter and longer – about scientists who contributed to the development of target scientific concepts and theories. These vignettes often speak both to the scientists' contributions and/or their personal stories. There also are descriptions of historical experiments and the players involved, reproductions of historical images, and illustrations that showcase original publications, instruments, events, and places. Overall, these historical materials are "boxed" in some fashion so as to clearly demarcate them from the rest of the text and most often – though not always – are presented as "contained" or stand-alone additions. A student can go through such textbooks and learn scientific concepts without having to go through these historical materials, which rarely translate into connected historical narratives related to the complex development of scientific concepts and theories. Science textbooks have been criticized for their revisionist and/or over simplistic treatment of HOS. Thus, it is not hard to understand why science teachers rarely accord significance to HOS as a separate instructional outcome, which warrants that they develop HOS-specific assessments. In this regard, it should be noted that there are a few examples of more carefully planned inclusion of HOS in instructional materials, such as the HOSC, that have used what could be characterized as an explicit-reflective approach to effectively use HOS to teach about nature of science and scientific inquiry (Abd-El-Khalick 2012).

HOS as a Context for Formative and Summative Assessments

Instead of HOS-specific assessments, attention to HOS has more often been discussed as a context or instructional approach for students to further develop their understandings of nature of science, scientific inquiry, science as a human endeavor, and the cultural contributions of science. Regarding assessments specifically, many instruments related to nature of science have referenced HOS as a context for questions. Such instruments include the *Conception of Scientific Theories Test* (Cotham and Smith 1981) and *Views of Nature of Science Questionnaire* (Lederman et al. 2002).

As described above, HOS is a way to demonstrate how science is a human endeavor, a way to teach about nature of science through explicit/reflective means. Historical cases demonstrate how knowledge has progressed, been refined, and even dramatically changed through processes of observation, negotiation, and argumentation. Written quizzes, exams, and essays can examine learners' recollection and interpretation of factual events but, more importantly, also can assess learners' understanding of the rationale for how scientific events progressed within the cultural and human context. Historical case studies are useful contexts for teaching but can also be used for assessments, both formative and summative.

Assessments based on HOS can help students explicitly draw connections between those events and scientific inquiry and nature of science. For example, historical episodes such as understanding the structure of DNA provide a context for assessing the details and significance of the scientists and investigations that lead to the creation, rejection, recreation, and eventual acceptance of the DNA structural model. Appropriate assessments based on this historical case include asking learners to explain:

What empirical data were used in the process of developing the model?

What assumption did the various groups of scientists make? How did these assumptions influence their research?

How did inference and creativity play a role in model development and critique?

Who were the scientists involved and what perspectives and methods did they bring to bear on the study of DNA structure?

How, if no one had ever directly seen DNA, could models be created and a single one eventually be accepted within the scientific community as a valid scientific model with explanatory and predictive value?

In these ways, HOS cases can assess learners' understandings of the science concepts and, more importantly for meaningful scientific literacy, can prompt learners to explain how the cases represent various aspects of scientific inquiry and nature of science. Other examples of how HOS can be used to assess nature of science views can be found in the "► NOS, Measurement of" entry in this encyclopedia.

Cross-References

- ► Assessment: An Overview
- ► Epistemic Goals
- ► Epistemology
- ► Nature of Science, Assessing of
- ► NOS, Measurement of
- ► NOS: Cultural Perspectives

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Hobbies

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Keywords

Leisure pursuits

People's regularly occurring interest-based recreational activities are called hobbies. Hobbies are leisure pursuits, in which adults and children have persistent engagement, outside of work. People who pursue hobbies are called hobbyists. Hobbyists engage in their hobbies because of interests about a topic, to experience design or development challenges, and/or the desire to participate in the hobby's activities or affinity group.

A hobby can include similar activities to a profession, but a hobby can be differentiated from work because a person engaged in a hobby maintains an amateur status. Additionally, while a person may derive a benefit from a hobby, the hobby does not provide a livelihood. However, depending on the hobby, hobbyists can also achieve a material reward or increased social status as a result of their hobby activities, including achieving leadership within affinity organizations, advancing in rank in an informal society, gaining a badge or other external recognition, and giving informational talks about their hobby at societies, museums, schools, or fairs or festivals.

Science hobbies are one kind of free-choice science learning (Falk and Dierking 2002) where people choose to make significant personal investments in a topic of interest. In this way, hobbies are part of a system of everyday science learning opportunities across the lifespan (Bell et al. 2009). Importantly, hobbies are the everyday science activities that are driven by the individual's interests rather than by the objectives of social organizations and institutions. Science-related hobbies can be directly or indirectly connected to subdisciplines of science. Science-related hobbies include bird watching, building model aircraft, stargazing, fossil collecting, gardening, rock collecting, traveling to national parks or international wildlife refuges, reading science nonfiction books, building electronic devices, raising animals, and nature photography.

To support their hobby interests, science hobbyists seek out and learn from a myriad of community and personal resources. A person may take a class or workshop from a university, an association, a community-based organization, a private firm, or a tutor, but hobbies are sustained outside of formal education through personal enthusiasm, curiosity, and interests that align with a set of informal activities. Hobbyists learn from and about various scientific resources: books, online media, specialized language, and scientific equipment. Often, a hobbyist maintains a personal collection of relevant scientific objects or tools to support their activities. Hobbyists gain knowledge about their hobby by attending science cultural institutions (such as zoos or other museums) or by participating in affinity organizations (like the Audubon Society, astronomy societies, or online forums) that overlap their hobby interests. Hobbyists may also learn more through an informal social circle by engaging with events that support increased participation in hobby activities. For example, some science hobbies include participating in engineering or technological practices where people learn to build their own equipment (as in telescopes, model rockets, or ham radios) or create technologies to support their engagement (as in websites, databases, or applications).

Based not only on the nature of the hobby activities but also through the intentions of hobbyists, hobbies have different relationships to biology, chemistry, physics, and other science domains. Science may not start as an aspect of a hobby, but over time, a person may bring in more science as they gain skills in their hobby. The hobby may involve science knowledge and practices, even if the hobbyist is not intending for their hobby to be a science-related hobby. For example, gardening may be started for reasons other than science, such as providing food for a family. But for some hobbyists, gardening overlaps with science as the hobbyist gardeners refine their knowledge of plants, soil, and ecosystem interactions by including beneficial insects instead of a pesticide. For other hobbyists, science may be a driving reason for their engagement, such as reading nonfiction books about the lives of scientists. Similarly, a child's interest in a topic may drive a family to participate together in a shared hobby related to science. A young child's interest in insects may spawn a hobby that becomes a family endeavor with the reading of many books, family trips to museums, watching nature documentaries, attending public programs, outdoor exploration to develop a specimen collection, Internet research at home and the library, and participation in specialized summer camps.

Research has shown that hobbies can provide people with opportunities for learning new science content and practices (Bell et al. 2013). Hobbies also provide access to other key educational outcomes: social development, opportunities to display expertise, enhancement of leadership skills in clubs, communication ability, and the development of identity towards science, education, and or science education.

Cross-References

- ▶ Citizen Science
- ▶ Communities of Practice
- ▶ Interests in Science
- ▶ Learning Science in Informal Contexts
- ▶ Lifelong Learning

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Humanist Perspectives on Science Education

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Keywords

Cultural emphasis; Human values; Humanistic policy and perspectives

During and ever since the formal inauguration of an Anglophone school science curriculum in 1867 (England) and 1893 (United States), ideology-based power struggles among science educators and stakeholders have animated school science policy, practice, and research. These struggles have often been identified in terms of two pervasive camps:

- Humanistic perspectives that promote practical utility, human values, and a connectedness with societal events to achieve inclusiveness and a student orientation
- A traditional perspective that promotes professional science associations, the rigors of mental training, and academic screening to achieve exclusiveness and a scientist orientation (Aikenhead 2006, p. 22)

The term "traditional" simply signifies which side won the struggle in 1867 and 1893 and became the status quo, which today is often recognized as science, technology, engineering, and mathematics (STEM) programming, a pipeline to STEM-related professions. This preprofessional training goal contrasts with the humanistic school science goal of students' preparing for responsible savvy participation in their everyday adult lives increasingly affected by science and technology.

The intervening years since 1893 have witnessed a variety of social, economic, political, and educational forces that have promoted various types of humanistic perspectives for school science, thereby, challenging the traditional status quo (Pedretti and Nazir 2011). One such challenge arose from a pluralist multiscience movement (Ogawa 1995; McKinley 2007) that fine-tuned the term "science" into "Eurocentric science" (ES) or "Western science," to make explicit its cultural roots anchored mainly in Euro-American cultures. Humanistic school science has always included scientific content and processes, but it gives significant attention to *the context* of such content and processes and to the context of learners. A humanistic school program encompasses both STEM and humanistic aspects, while traditional STEM programs exclude humanistic aspects, by and large.

Humanistic perspectives have produced such innovations as applied science courses, historical case studies, the nature of Eurocentric science (NOS), science-technology-society-environment (STSE), socio-scientific issues (SSI), citizenship education, cross-cultural or multicultural school science, and political activism. These innovations share a common interest in dealing with values, the social aspects of Eurocentric science (ES), the culture of ES, and the human character of ES revealed through its sociology, history, and philosophy.

No matter what aspects of humanistic perspectives are implemented, research studies clearly show over five decades that measures of students' ES content achievement are either improved or unaffected as a result. A synopsis of research into humanistic perspectives implemented in school science is found in Aikenhead (2006).

School science, whether traditional or humanistic, has been described using various schemes. Three are mentioned here to articulate the meaning of humanistic perspectives of science education. The first scheme is Roberts's (2011) conceptualization of two visions of scientific literacy, that is, two competing purposes for learning ES. Vision I is an inward-looking understanding of scientific disciplines themselves, and it represents a commitment to developing a potential scientist pool. Vision II is an outward-looking understanding of the roles that ES plays in human affairs, and it focuses on the relevance of ES to "a variety of science-related situations that confront adults as parents and citizens" (2011, p. 14). Vision II certainly resonates with humanistic perspectives. Visions I and II are neither dichotomous nor a continuum. A Vision I school science is rather homogenous in the sense that it is consistent enough worldwide to have international assessments conducted and be taken seriously by many governments. A Vision II school science is highly heterogeneous because it will always encompass aspects of Vision I; and its Vision II aspects are multifarious, just as humanistic perspectives are.

Importantly, both Visions I and II are only concerned with *Eurocentric* science for scientific literacy. This eliminates other cultural ways that rationally and empirically describe and explain nature, such as various neo-indigenous sciences and Indigenous ways of knowing nature found worldwide (Aikenhead and Ogawa 2007). Examples of neo-indigenous sciences include Islamic science, traditional Chinese science, a Japanese way of knowing seigyo-shizen, and the long-standing local knowledge of nature held by non-Indigenous farmer-hunters.

The exclusion of an Indigenous understanding of nature from school science is being challenged in a number of countries where Indigenous peoples (e.g., American Indians; the Mäori in Aotearoa, New Zealand; and First Nations in Canada) have suffered colonization in the past and neo-colonization today that bring economic, social, political, and cultural oppression (McKinley 2007). Local place-based ways of knowing nature by Indigenous peoples have a legacy of survival for tens of thousands of years and highlight sustainability and balance in their understanding of nature, in addition to other attributes of Indigenous worldviews (Aikenhead and Ogawa 2007).

A cultural emphasis in school science provides a broader lens for humanistic policy and practice. It considers the culture of ES, the culture of school science, students' cultural self-identities (Indigenous and non-Indigenous), and the community's cultural understandings of the physical world (Indigenous or neo-indigenous). This emphasis produces cross-cultural or culturally responsive school science, which are aspects of humanistic school science receiving widespread attention today. Where culturally responsive school science has been implemented, academic achievement of students tends to rise because of their strengthened cultural self-identities. At the same time, students have access to a richer understanding of nature by being able to draw upon two coexisting, noncompetitive knowledge systems – Eurocentric and Indigenous or neo-indigenous (Aikenhead and Michell 2011). Rather than aiming for *scientific literacy* as Visions I and II do, cross-cultural school science for Indigenous and non-Indigenous students aims for *nature literacy* that embraces both scientific and Indigenous or neo-indigenous ways of knowing nature. When school science combines both ways of knowing nature, it becomes more natural for students to learn other content associated with humanistic perspectives of school science such as NOS.

A second scheme for describing school science focuses on the content to be taught and considers two related principles: relevance of that content and *who decides* what is relevant for students, today and in their future. The issue of who decides will determine the type of ES content taught in school science, as summarized in Table 1. Of the seven categories in Table 1, only one (wish-they-knew ES) describes traditional school science or Vision I. The remaining categories indicate ways of describing humanistic perspectives of science education. (Details of each category are found in Aikenhead 2006.)

A third scheme, which summarizes some of the previous discussions, emerges empirically from five decades of research by science educators who investigated humanistic innovations to traditional school science (Aikenhead 2006).

Humanist Perspectives on Science Education, Table 1 Who decides on relevance and the resulting type of school science content (Modified from Aikenhead 2006, p. 32)

Who decides what is relevant?	Type of school science content
Academic scientists, education officials, and some science teachers, who invariably choose ES canonical content	Wish-they-knew ES
People mainly in ES-related occupations and savvy citizens. Research has identified a wealth of general and specific educational outcomes not normally found in a traditional school science but found in ES-related occupations and everyday events and issues	Functional ES
ES-related experts who interact with the general public on real-life events and who know the problems the public encounters when dealing with these events	Have-cause-to-know ES
The general public who has faced real-life problems or decisions related to ES. What ES content did they need to know to resolve their problem or make a decision?	Need-to-know ES
People who produce the media and internet sites and who draw upon sensational and controversial aspects of ES and technology to achieve motivational value for readers and viewers	Enticed-to-know ES
Students themselves express an opinion on what ES topics would be of interest to study. What are they curious about?	Personal-curiosity ES
Interpreters of culture, who can collaboratively combine aspects of ES culture with local ways of understanding ES and nature, in order to teach features of local, national, and global cultures. This category can simply include a combination of categories above. It is exemplified by, but not restricted to, STSE, SSI, and cross-cultural school science that includes Indigenous or neo-indigenous content	Sciences as culture

A humanistic perspective, however, is not the only researched innovation to have challenged the status quo of school science. But these other innovations (e.g., constructivism, project-based learning, and technology-design courses) rest on more specific educational agendas than the general agendas that guide humanistic perspectives of school science. Any one or combination of the following items identifies a feature of a humanistic school science program, which would not be found in traditional school science to any significant degree:

- Induction, socialization, or enculturation into students' local, national, and global communities that are increasingly shaped by ES and technology
- Citizenship preparation for the everyday world
- Savvy citizens cognizant of the personal, social, economic, political, and cultural dimensions of scientific practice and its consequences
- Attention to several types of Eurocentric sciences, known in the literature as established "core science" versus tentative "frontier science," and/or citizen science
- Pluralistic cultural approaches reflecting understandings of nature held by major cultures worldwide, such as Indigenous and neo-indigenous ways of knowing nature
- Knowledge *about* ES and scientists (contrasted with scientific knowledge)
- Moral reasoning integrated with values, human concerns, and scientific reasoning, where appropriate
- Seeing the world through the eyes of students and significant adults and teaching from that orientation
- Learning by interacting with the everyday world, which results in intellectual achievement, personal change, forming or enhancing one's self-identities, recognizing sociopolitical power, or engaging in practical or social action
- Playing in the culture of ES as an outsider, rather than forming a ES self-identity as an insider
- Acquiring an equity and social justice stance for political activism

One issue may never be resolved: At what point do we label a school science course "humanistic"? In other words, *to what extent* must any of these aspects of humanistic perspectives (or combinations thereof) appear in a classroom in order to characterize a school science experience for students as being humanistic rather than traditional? A school science experience could be superficially, moderately, effectively, or intensely humanistic for students. If we enhanced a traditional science program to be only superficially humanistic, we would not expect it to make a difference to a student's experience. For example, evidence from several recent studies demonstrates the negative impact of traditional school science on students' perceptions of innovations such as SSI: "Students saw the same activities [the SSI innovation] as a simple extension of what ordinarily transpires in science classrooms" (Sadler 2009, p. 36); a conclusion verified by a very extensive study of students' and teachers' perceptions of what transpires in their science classrooms (Wood et al. 2009) and verified in a review of research into students' identity in science learning (Shanahan 2009).

Perhaps a change to the culture of the science classroom or to the culture of school science itself is required before a humanistic innovation causes students to experience their science class as humanistic school science. A defining question would be: Do students understand Eurocentric science as one of several cultural endeavors for understanding nature, which is embedded within a social milieu of society and conducted by various social communities of scientists whose scientific training enculturated them into viewing the physical world according to the subculture of their discipline or paradigm? "Science is a very human activity. It involves human actors and judgments, rivalries and antagonisms, mysteries and surprises, the creative use of metaphor and analogy. It is fallible, often uncertain, and sometimes creatively ambiguous" (Lemke 1990, p. 134).

Cross-References

- ▶ Acculturation
- ▶ Alienation
- ▶ Borders/Border Crossing
- ▶ Citizen Science
- ▶ Classroom Learning Environments
- ▶ Cultural Influences on Science Education
- ▶ Cultural Values and Science Education
- ▶ Culturally-Relevant Pedagogy
- ▶ Culture and Science Learning
- ▶ Curriculum
- ▶ Curriculum and Values
- ▶ Curriculum Development
- ▶ Curriculum Emphasis
- ▶ Curriculum in Play-Based Contexts
- ▶ Curriculum in Teacher Education
- ▶ Curriculum Movements in Science Education
- ▶ Curriculum Structure
- ▶ Environmental Education and Science Education
- ▶ Environmental Teacher Education
- ▶ Ethnoscience
- ▶ Learning of Science – A Socio-Cultural Perspective
- ▶ Multiculturalism
- ▶ NOS, Measurement of
- ▶ NOS: Cultural Perspectives
- ▶ Relevance
- ▶ School Environments
- ▶ Scientific Values
- ▶ Sociocultural Perspectives and Gender
- ▶ Socio-Cultural Perspectives and Characteristics
- ▶ Socio-Cultural Perspectives on Learning Science
- ▶ Socioscientific Issues
- ▶ Teaching and Sociocultural Perspectives
- ▶ Values
- ▶ Values and Indigenous Knowledge
- ▶ Values and Western Science Knowledge
- ▶ Values in Science

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Hypothetico-deductive Method

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The hypothetico-deductive (HD) method, sometimes called the scientific method, is a cyclic pattern of reasoning and observation used to generate and test proposed explanations (i.e., hypotheses and/or theories) of puzzling observations in nature. The goal of the method is to derive useful knowledge – in the sense that causes are determined such that reliable predictions about future events can be made. The term "method" may be somewhat misleading as use of the HD method does not insure success. The method may fail for a variety of reasons, not the least of which is that the "correct" causal explanation may not occur to the scientist, effective ways of testing proposed causes may not occur to the scientist, and proposed tests may not be feasible with available technology or funding. The following seven steps and four inferences are involved:

1. Scientists undertake explorations that lead to puzzling observations. For example, in 1610, Galileo used his newly invented telescope to observe three never-before-seen points of light near Jupiter. Thus, a causal question arose: What caused the three points of light?
2. The scientist then uses his or her store of declarative knowledge and *abduction* (i.e., analogical reasoning) to generate one or more tentative explanations (e.g., like previously seen fixed stars, Galileo thought that perhaps the three points of light were also fixed stars).
3. Next, the scientist uses *retroduction* to subconsciously test the initial explanation against prior observations (e.g., if the three points of light are fixed stars, then their relative positions around Jupiter should be random like other fixed stars. But the points of light appear along a straight line across the middle of Jupiter. Therefore, via retroduction, the fixed stars explanation is contradicted).
4. When retroduction leads to the rejection of an initial explanation, the scientist again uses abduction to generate another explanation (e.g., perhaps, like the Earth's moon, the three points of light are moons orbiting Jupiter).
5. After a successful retroductive test of a prior explanation (e.g., if the lights are orbiting moons, then they should appear in a straight line across the middle of Jupiter; they do appear that way; therefore, the orbiting moons explanation is supported via retroduction), the scientist imagines a test and uses *deduction* to generate one or more expected results (i.e., expectations/predictions) about what subsequent observation(s) should occur – assuming that the proposed explanation is correct and the test is conducted as planned (e.g., if the points of light are orbiting moons and I, Galileo, observe their positions on subsequent nights, then sometimes they should appear to the right of Jupiter, and sometimes they should appear to the left. But they should always appear on a straight line across the middle of Jupiter).
6. The scientist then conducts the imagined/planned test and makes the relevant observation(s) (e.g., on subsequent nights, Galileo

observed the points of light sometimes to the right of Jupiter and sometimes to the left but always on a straight line across the middle).

7. Lastly, the scientist compares expected result(s) with observed result(s) and uses *induction* to draw a conclusion about the veracity of the tested explanation (i.e., if expected and observed results match, then the explanation is supported; if expected and observed results do not match, then the explanation is contradicted). In Galileo's case, his subsequent observations matched predictions deduced from his orbiting moons explanation and its planned test. Therefore, he found support for that explanation and he then proclaimed to the world that he had "discovered" Jupiter's moons. Additional historical examples can be found in Lawson (2010).

Use of the HD method does not result in certainty. In other words, neither proof nor disproof is possible. This is because two or more different explanations may lead to the same prediction; thus, an "incorrect" explanation may appear to be supported – what is called a false positive or what statisticians call a Type I error. On the other hand, a "correct" explanation may appear to be contradicted due to a faulty deduction, a faulty test, or due to invalid evidence – what is called a false negative or what statisticians call a Type II error. Nevertheless, the collective and open nature of the scientific community helps insure that "correct" explanations are eventually found and "incorrect" ones are eventually rejected.

Scientists are not the only people who reason in a hypothetico-deductive manner. All normal adults do, at least in some contexts some of the time. However, the pattern of HD reasoning remains subconscious for most adults. And without a conscious guide to reasoning, several subconscious biases and omissions may derail the process and produce faulty conclusions. These subconscious biases and omissions include cherry picking, confirmation bias, anchoring, outcome bias, wishful thinking, affect bias, and premature closure (e.g., Kahneman 2011). For an example of how these and other biases may derail physicians from correctly diagnosing illnesses, see Lawson and Daniel (2011). Hence, a key goal for science teachers is to help students become more aware of the HD method as well as the biases and omissions that can derail its effective use.

Cross-References

- ▶ Empiricism
- ▶ Nature of Science
- ▶ Scientific Literacy
- ▶ Scientific Values

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ICT in Play-Based Contexts

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Keywords

Curriculum; ICTs; Play; Technologies

Introduction

Although play-based contexts may be evident across a range of educational settings, they are commonly associated with the provision of early childhood education (defined as education for young children aged birth to 8 years). Play-based contexts in this area of education are focussed on the use of play and play-based experiences as a basis for supporting young children's learning and development. The use of play and play-based learning in early childhood education is highly contentious and involves debates regarding the extent to which children should be able to play without adult intervention, the role of adults in co-constructing knowledge with young children, and issues associated with power and social relationships between peers, adults, and children. Play-based learning also invokes discussion regarding the gender dimensions of play and how these are articulated via curriculum that uses play as a basis for supporting learning. Such debates are informed by a range of theoretical perspectives including sociocultural theory, childhood sociology, critical theory, poststructuralism, and feminist poststructuralism. There is an increasing awareness of the need to understand play relationally in terms of the context in which it is located and therefore experienced by children, families, and educators (Brooker and Edwards 2010).

While ICTs are not commonly discussed in early childhood education in terms of critical or poststructuralist debates about play, they are increasingly evidenced in understandings of play that focus on children's experiences of society and their social and cultural contexts. Understanding ICTs in terms of children's social and cultural experiences has informed a shift in thinking regarding the use of ICTs in play-based contexts. Early debate regarding the use of ICTs in early childhood education suggested that technologies would be damaging to young children's development as they potentially hindered children's opportunities for engaging in the range of active play-based activities that were viewed as important for supporting learning. However, large-scale research identified multiple reference points for young children's technology use within the family context, including the use of mobile technologies, Internet use, television and DVD viewing, and the use of handheld consoles and computers (Vandewater et al. 2007). In the family context, technology use commonly includes interaction with peers and/or siblings, moderation of use by adult-imposed rules, and levels of

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access associated with socioeconomic status (Stephen et al. 2008).

Counterarguments against the rejection of ICTs in play-based contexts began to emphasize the role of ICTs in society in general and in children's family and home experiences more specifically. This suggested that ICTs should have a place in play-based contexts as young children were increasingly using technologies in their broader social settings. Some of this discussion was later contextualized in relation to the idea of "digital natives" (Prensky 2001) and the "digital disconnect" (Levin and Arafeh 2002). These propositions suggested that young children were autonomous users of technologies having been born into a digital era and that their home experiences were so technologically orientated that they were increasingly disconnected from their less technologically enriched educational settings. In early childhood education this was considered particularly marked given the emphasis on play-based experiences that valued "active" play over the use of different technologies. However, these views have since been moderated by the suggestion that concepts such as "digital natives" and the "digital divide" more accurately reflect discursive constructions of children in contemporary times based on generational assumptions about how all people use technologies (Selwyn 2009), than they are on a reality necessarily experienced by the majority of the world's young children.

Use of Technology

Comprehensive research into young children's technology use in both family and early childhood education settings in Scotland by Stephen et al. (2008) suggested that young children learned to use ICTs via the same support structures that enabled other aspects of their learning, such as the acquisition of language. This included observational learning (i.e., watching adults or older siblings use a game console), scaffolded learning (i.e., being assisted in turning on the television), and/or exploratory learning (i.e., examining the properties of a computer game). Stephen et al. (2008) also noted a range of similar ICTs appearing in home and early learning settings, resulting in a definition for ICTs in play-based contexts:

> By ICT we mean not only desktop computers, laptops and peripherals but also interactive television, digital cameras, DVDs, mobile telephones, games consoles, electronic keyboards and toys that simulate 'real technology' such as toy laptops or barcode readers (Plowman and Stephen 2008 cited in text). This definition allows us to incorporate technologies that are both interactive and communicative and which are particularly appropriate for preschool age children because they do not rely on using text or a keyboard and are more ergonomically suited for three to five year old children. These technologies are present in many preschool playrooms and represent the range of resources available at home (p. 100)

As this definition (above) suggests, ICTs are increasingly acknowledged as having a functional role in play-based contexts. This includes via the use of "toy" technologies for supporting children's pretend play and/or the use of "real" technologies used for communicative or interactive purposes. Ways in which "real" technologies are used in play-based contexts include using open-ended software on desktop computers, providing children with access to video cameras to make movies associated with their dramatic play, and using applications ("apps") on touch screen tablets to support the development of problem solving, literacy, and numeracy skills. Digital cameras are also commonly employed by educators to document children's learning and are increasingly used in research with young children to help children record their perspectives on their learning environments. Technologies in play-based contexts have also been shown to support pro-social behavior and opportunities for collaborative engagement amongst young children. "Toy" technologies are used in traditional areas of play-based contexts, such as the "home corner" where toy mobile phones and "scanners" are used to create role play experiences for children, such as "going shopping." In literacy corners defunct computer screens and keyboards frequently form part of a role play scenario alongside the use of real and more traditional tools such as pens, paper, and environmental print to support children's emergent meaning making.

The extent to which "real" and "toy" ICTs are effectively integrated within play-based curricula is often dependent on the skills and attitudes of individual educators. Skills are concerned with technological abilities, such as understanding how to operate hardware, use different software, and access the wireless enabled technologies. Attitudes are associated with how educators understand the role of technologies in play-based contexts and what this means for children's learning. A common claim in the early childhood literature is that ICTs would be more widely and effectively used in play-based contexts if educators were provided with better technological support and greater access to professional development about how to use technologies with young children. This argument derives from concerns that many early learning settings do not have access to formalized information technology support services that would allow teachers to respond to problems in using technologies with greater confidence. It is also associated with the idea that teachers require further understanding about how to integrate technologies more fully into play-based contexts. This results in the situation whereby "real" or "toy" technologies may be functionally present in the play-based context, and yet not strongly connected with how teachers use play to support children's learning.

Curriculum

Interestingly, this latter point is evidenced in key international early childhood curriculum documents which tend to separate descriptions of play as a basis for learning from descriptions of technology as an important part of children's lives. For example, the English *Framework for the Early Years Foundation Stage* (Department for Education 2012) describes play as "essential for children's development, building their confidence as they learn to explore, to think about problems, and relate to others. Children learn by leading their own play, and by taking part in play which is guided by adults." (p. 6). In contrast, technology is described as a specific area of learning where children "recognise that a range of technology is used in places such as homes and schools. They select and use technology for particular purposes" (p. 9).

The definition of play does not acknowledge technologies, and the definition of technologies does not incorporate ideas traditionally associated with play, such as exploration, problem solving, and/or social relationships. This situation occurs in other curriculum documents including the *Nurturing Early Learners: A framework for a kindergarten curriculum in Singapore* (Ministry of Education, 2012), New Zealand's *Te Whariki Early Childhood Curriculum* (Ministry of Education 1996), and Sweden's *Curriculum for the Preschool* (National Agency for Education 2006). In some early childhood curriculum documents, play is positioned as having a prominent role in young children's learning and development, while technology and ICTs barely rate a mention. This is the case in the *National Curriculum Guidelines on Early Childhood Education and Care in Finland* (Ministry of Social Affairs and Health 2004) and in the (American) *Developmentally Appropriate Practice Guidelines for Practice* (National Association of the Education for Young Children 2006). Clearly understandings about how technologies relate to play as a basis for learning need further consideration.

Conclusion

While research has established the role of technologies in children's lives (Vandewater et al. 2007) and how children learn to use technologies (Stephen et al. 2008), more research is needed to determine how technologies and play can be understood as an integrated concept in play-based contexts. This includes teachers and curriculum documents being able to talk about and recognize technological activity in play-based terms, rather than continuing to abstract technologies from the core work of play as a basis for learning. This shift in research focus would be significant as it would be more strongly aligned with understanding the nature of children's play in contexts that naturally include technologies, than it would be on either what technologies children commonly use or how teachers can be best supported to use technologies with young children. Understanding the nature of technological play therefore represents a significant aspect of future research associated with the use of technologies in play-based contexts.

Cross-References

- ▶ Early Childhood Science Teacher Education
- ▶ Learning in Play-Based Environments
- ▶ Teaching in Play-Based Contexts

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Identity

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Keywords

Beliefs; Formation; Goals; Values

Identity defies one definition; it can be defined legitimately, with rigor, in different ways. Complicating the issue is that theories of identity did not emerge in education or even in educational psychology. Thus, problems arise when science education scholars do not attend to the disciplinary roots, ontological and epistemological assumptions, implied methodologies, and limitations of the ways they use identity. This entry describes two distinct ways of defining and studying identity: (1) individual/developmental and (2) situated/identity in practice.

Perspective #1: Individual/Developmental

Since the early days of psychology, scholars have wrestled with the concept of self. When psychologists focus on identity, some important elements include goals, values, beliefs, self-efficacy, belonging, and/or roles. Erickson's (1968) work on ego identity development, as expanded by Marcia (1980), stressed four developmental stages an individual goes through as one moves from exploration of an identity to full commitment. Failure to reach such a commitment results in either a diffused or foreclosed identity while tarrying in the process of exploration lands one in a state of moratorium.

Underlying Assumptions and Methodological Implications

Some or all of these assumptions are often part of the literature that describes identity from an individual/developmental point of view.

- Identity is something to achieve. With this perspective, the researchers will examine *identity formation*, with the ontological assumption that there is such a thing as an achieved identity. A study that isolates variables affecting identity is one example of how this assumption plays out methodologically. Identity is an established state to which researchers can appeal in order to make causal claims.
- Identity is developmental. One moves toward more and more sophisticated and stable

versions of self, through stages. Scholars researching identity with this assumption use the phrase *identity commitment* and aim to define stages of such development where one's identity in a specific area develops to an advanced or more sophisticated form.
- Identity is a compilation of/affected by personal attributes, internal schemas, and/or psychological processes (e.g., goals, beliefs, and/or values). Though it may be shaped by others, identity is primarily an emic construct. From this perspective, the individual – how one sees oneself and the choices one makes in response to one's environment – is taken to be the primary unit of analysis. Context is studied in as much as it affects the choices one makes and the individual's view of oneself. One methodological implication is that the researchers' role is to uncover or mine individuals' self-understandings, often through surveys and/or structured interviews. This assumes that relevant aspects of identity are reified, with participants able to describe and define these self-understandings.

Critiques

Interestingly, much of the science education literature that claims an identity perspective eschews a purely individual/developmental lens, describing it as too static, decontextualized, and agentic. However, though science educators may not claim this individual/developmental perspective, their methodologies sometimes imply it. One marker of an individual/developmental perspective on identity is operationalizing it as a "thing" to be studied, developed, and/or strengthened. Studies that examine the factors that affect science identity, science teacher identity, or academic identity, for instance, often take up many of the assumptions outlined above.

A primary critique of the individual/developmental lens is that it simplifies the complex ideas of "being somebody" and "defining oneself" to emphasize clean categories of self-understanding and essentialist views of self. The emphasis on achieving a "coherent" identity does not adequately account for performances and understandings of self that shift from context to context and that might involve moments of improvisation and imagination. Units of analysis that prioritize individual mental functioning also means that agency is overemphasized. Processes of "becoming," in this view, seem to be more matters of choice and ignore larger social, cultural, and historical structures that shape individuals' opportunities to take up certain identities. There is not a lot of analytic space, in the individual/developmental views of identity, to examine the ways that structures like race, class, and gender bear down on individuals' everyday practices, enabling and constraining their identities. We have a say in who we become but only a limited say (Holland et al. 2001).

Perspective #2: Situated/Identity in Practice

Those who draw on a situated/identity-in-practice perspective frame identity as a way of being in the world (Wenger 1998) that influences and is influenced by local and global social, political, and historical processes. Identity emerges in practice, through acts of authoring/performances of self and positioning by others and by leveraging historical resources. Authoring involves performing oneself in particular ways and/or intentionally asserting identities in social settings. When people author identities, they perform different behaviors, speeches, and artifacts deemed appropriate in a setting, drawing cultural resources from the past, as well as those available in the immediate, local setting to do so. Successful acts of authoring are constrained by individual imagination and improvisation, accessible local and historical resources, and others' (personal, institutional, societal) positioning. An individual can be an unwitting or unwilling recipient of others' acts and be ascribed an unwanted identity because of her race, class, gender, sexuality, religion, nationality, age, or size.

A primary ontological assumption of a situated/identity-in-practice view, then, is that identity exists, not as a "thing", but in the continual work of making and remaking the self in everyday practice. Some argue that tools one uses to author oneself can be used habitually and, over time and context, can be leveraged for self-control and change (e.g., Holland et al. 2001). In other words, an identity-in-practice view does not have to be inconsistent with a view that assumes some directionality and consistency.

Wenger (1998) juxtaposes an identity-in-practice view with "self-image" by arguing "Who we are lies in the way we live day to day, not just what we think or say about ourselves, though that is of course part (but only part) of the way we live. Nor does identity consist solely of what others think or say about us, that that too is part of the way we live" (p. 151). Though reifications of self, like narratives, categories, roles, and positions, are important in constructing identity, those categories take on meaning in practice. Wenger describes identity as "a layering of events of participation and reification by which our experience and its social interpretation inform each other" (p. 151). Therefore, identities in practice can be stabilized and destabilized over time through the interactions between one's identity authoring and reception by a given community of practice.

Identity in practice has been an important concept in recent science education research because it represents a different way of viewing learning. Instead of defining it as a solely cognitive activity, learning involves new ways of talking, acting, describing oneself, and relating to others. Learning is not separate from identity work; they are inextricably connected. As actors participate in a science learning setting, they are often engaged in identity-related activities to perform themselves as particular kinds of people and make meaning of those performances in certain ways: leveraging resources from past experiences and invoking images of future participation. A situated/identity-in-practice view draws our attention to a learner's increasing participation in a community of social practice.

A situated perspective on identity has its roots in a number of theories, including but not limited to social practice theory (Holland et al. 2001; Lave and Wenger 1991), cultural historical activity theory (Engeström 2001), performance-based notion of identity (Goffman 1959), and Bronfenbrenner's ecological theory (1979). Though each of these perspectives differs slightly, a common thread is that microlevel (local), mesolevel (institutional), and macrolevel (societal) influences enable and constrain one's identity work.

An important shift from the individual/developmental notion of identity to the situated/identity-in-practice notion of identity is that, in the latter case, identity is often examined analytically as a *process* or as *identity work* or as *identity trajectories*. Instead of viewing identity as an achievement, it is viewed as an *ongoing* achievement. The route of such identity trajectories is also not straightforward as identities in the moment along a trajectory can offer different momentum toward or away from a particular recognized identity.

Underlying Assumptions and Methodological Implications

Some or all of these assumptions are often part of the literature that describes identity from a situated/identity-in-practice point of view.

- Identity emerges in everyday practices. Practices (like discourse, ways of acting, and interacting) are locally enacted but have historical longevity, meaning, and political consequence. Methodologically, this means that data collection must involve some acknowledgement and understanding of the taken-for-granted meanings of "science" and "science person" that shape what counts as normal, errant, or extraordinary engagement in practice.
- Identity is a way to account for structure and agency. Identity accounts for individual agency and choice as well as social, political, cultural, and historical structures that constrain individuals' possibilities. People act as both social producers and social products (Holland et al. 2001). This implies an analytic lens that allows for a zooming in and out to understand one's identity work.
- Identity is not simply what an individual says about her relationship to, abilities in, or aspirations regarding science or any other social group. It is not purely an individual achievement, nor is it an entirely emic construct.

It arises out of constraints and resources available in local and global contexts. This means that identity studies must employ multiple methods to understand these multiple perspectives.

- Identity work requires the participation of others (Gee 2000–2001). One cannot pull off being a particular kind of person (enacting a particular identity) unless one makes visible to (performs for) others one's competence in relevant practices and, in response, others recognize one's performance as credible. Since one is often a member of multiple communities of practice, one may have to "code switch" when traversing new cultural contexts, shifting her/his performance to signal cultural membership.

Critiques

The strength of situated identity/identity in practice as an analytic lens in science education – i.e., highlighting the fluid nature of identity work within the confines and affordances of figured worlds – also presents a significant challenge. Since identities are always negotiated and in-the-making, they become impossible to isolate or name. Researchers can observe identities in the moment as evident in performance and engagement in practice, and extensive field time is required to track how students' identity work evolves and which identities in practice are stabilized or destabilized based on available and historical resources and reception/recognition by the classroom community.

Cross-References

- ▶ Activity Theory and Science Learning
- ▶ Identity of Teacher Educators

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Identity of Teacher Educators

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Identity

A professional identity has been variously described as an occupational group's self-image, their sense of place in the world, and their idealized, desired, or valued selves. A professional identity outlines and describes how individuals and groups see themselves being and operating in their work or occupational contexts. It comprises the special occupational beliefs, actions, and knowledge that best defines the "kind" of person that individuals or groups see themselves as being, wanting to be, and acting like in their occupation, and it represents the desired and possible aspects of their occupational lives that they believe make them like or unlike other occupational groups in society.

Characteristics of Teacher Educators

The particular characteristics of a professional identity that have been advanced for teacher educators – those distinctive beliefs, behaviors, abilities, and contexts which distinguish and define them as an occupational group – include:

- A primary responsibility and role as a teacher of other teachers, as distinct, for example, from being a teacher of school children
- A comprehensive and practical knowledge of the theory and practice of teaching and learning and of education generally
- An ethicality of purpose and a strong sense of other-orientedness
- A view of teacher education as multidisciplinary in terms of its methods, but unique in the academy in terms of its "second-order" and recursive nature and content. Teaching about teaching is seen as fundamentally different as a practice to teaching about anything else.
- A commitment to an embodied pedagogy that prioritizes pedagogical method and process over content and involves real-time and ubiquitous modelling and articulation of the pedagogical process.
- A sense of living an occupational life on the margins of the various subcultures of education – a life lived, for example, between and across the cultures of teaching and research, practice and theory, curriculum implementation and policy development, schools and the academy, and so on.

Relevant psychological and social theories of (professional) identity include those of Erik Erikson, Pierre Bourdieu, Etienne Wenger, and James Gee. Recent studies focussed specifically on the professional identity of teacher educators include a special issue of the journal *Studying Teacher Education* dedicated to teacher educator identity (2011), much of the work of the self-study of teacher education practices (S-STEP) Special Interest Group (SIG) of the American Education Research Association, and a number of studies from the United Kingdom and the Netherlands of teacher educators' professional induction and ongoing professional learning.

Studies of professional identity are windows into the professional ideals of an occupational group. They are also studies of professional performance and occupational effectiveness. It has long been acknowledged that professionals' performance and effectiveness is directly influenced, among other things, by the levels of personal commitment that people make to their jobs as a genuinely *professionalized* activity – as vocations, as unique knowledge bases, and as distinct communities of experts. How teachers and teacher educators conceptualize their job as a "professional" activity directly affects how well they do it.

Cross-References

- ▶ Activity Theory and Science Learning
- ▶ Identity
- ▶ Pedagogy of Teacher Education
- ▶ Self-Study of Teacher Education Practices (S-STEP)

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Imagination and Learning Science

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Keywords

Creative thinking; Emotional engagement; Narrative thinking; Romantic understanding; Scientific creativity

Imagination is central to human thinking. In induction it is the imagination that helps bring some order to the elements of sense experience and intuition. And in deductive reasoning one has to go, through the use of the imagination (i.e., through suppositions, hypotheses and conjectures), well beyond what is actually present and what is actually noted. Despite its complex nature, imagination can be understood as the ability to form mental images and also to think in terms of possibilities (Egan 1992). The role that these abilities have played in scientific work, although not reported in scientific papers, can be found in the literature where scientists (e.g., Maxwell, Einstein, Planck, Feynman, Polanyi) talk about their own research or the development of scientific knowledge in general. Their views reflect the centrality of the imagination in science, whether the latter is viewed as a creative/artistic activity, that contributes to new ideas or as a daily laboratory practice that involves problem-solving, experimentation, etc. Perhaps it is van't Hoff's metaphor for the imagination as "the building material of science" that best captures the imaginative element inherent in the nature of science itself.

Gerald Holton is one of the very few who have written about the scientific imagination. In stressing the imaginative element of scientific work, Holton talks about three kinds of scientific imagination, namely, the visual, the metaphorical, and the thematic. The visual imagination in particular has played a catalytic role in scientific discoveries and the formulation of new theories and ideas. The history of science testifies to the fact progress in science is made possible because of scientists' ability to visualize and to create analogies. Galileo's and Einstein's thought experiments are perhaps best known for the power to illustrate their originator's ideas, while Young's analogy between sound and light, albeit an unsuccessful one, was decisive for our understanding of the wave nature of light. The role of the imaginative element needs to be acknowledged and recognized even in the thematic imagination, even though the imaginative element is not as evident as in the other two kinds. For as has been observed, it is the thematic imagination (i.e., the scientists' tacit or unconscious preconceptions and presuppositions) that helps shape and even determine scientific ideas, despite available evidence from empirical data or current theory that disagrees with these ideas (Holton 1996, 1998).

Imagination in science, as the ability to form mental images and visualize and/or to think in terms of various possibilities, has been directly or indirectly linked to scientific creativity. Indeed, scientific creativity presupposes the imagination (e.g., one can be imaginative without being creative, but one cannot be creative without being imaginative). This is so whether one considers the scientists' imaginative leaps, like those resulting in original ideas that contribute to scientific progress (e.g., Planck's mental leap to move from radiation itself to the radiating atom), or simply such thinking skills as problem-solving and inquiry, which scientists use in their daily work. The fact that "imagination" and "creativity" have been considered by both scientists and science educators to be two ideas that students should know in relation to the nature of science reflects the importance that science educators attach to imagination. This importance is also reflected in the view that imagination can make scientific creativity more concrete, thus offering more opportunities for a better understanding of the latter in the context of science education.

Scientific creativity, especially in the form of thought experiments through which knowledge can be acquired through mental manipulations alone, provides support for the central role of the imagination in conceptual change in science and contradicts the epistemology of empiricism that dominated the philosophy of science for the most part of the past century. Thus the recognition of the importance, if not the centrality, of the imagination in science education, came with the epistemological shift from empirical inductivism that took place during the last three decades of the twentieth century. Although some scientists and philosophers had long argued that scientific ideas (e.g., concepts, hypotheses, theories) are mental constructions and therefore they are not directly derived from observation data but are invented in order to account for these data, the role of the imagination in science education was acknowledged with the rise of constructivism, that is, an epistemology which criticized the standard, positivist, empirical view of science (see "▶ Constructivism").

Jerome Bruner's hypothesis concerning two distinctive but complementary modes of thinking, that is, the paradigmatic (or logico-mathematical) and the narrative, was decisive for the rediscovery of the importance of the imagination in thinking and learning. While the paradigmatic mode is concerned with the formation of hypotheses, with the development of arguments, and with rational thinking in general, the narrative mode is concerned with "verisimilitude," that is, lifelikeness, and the creation of meaning. It seeks explications that are context sensitive and particular (not context-free and universal), is entirely divergent, and employs literary devices, such as stories, metaphors, and hyperboles, in order to evoke meaning. Both modes of thinking are "natural," in the sense that under minimal contextual constraint, they come spontaneously into being (Bruner 1986).

The narrative mode of thinking has been considered central to science and science education. Metaphors and analogies (see "▶ Analogies in Science", "Mataphors for Learning") rely on the narrative mode. Even thought experiments are not simply visualizations (e.g., riding on a beam of light, free falling inside an elevator); they do have a narrative form (i.e., when one narrates the thought experiment), and through the listener's or reader's imagination, the situation that the narrative describes, no matter how realist or unrealistic that might be, becomes understood. In short, a thought experiment is always conveyed in a narrative form. What should be pointed out though is that the narrative mode is not as imaginative as one might think, since the paradigmatic mode tests ideas through the use of available evidence and logical arguments. And it is in this sense that the two modes of thinking are considered complementary.

The hypothesis concerning the existence of the narrative mode of thinking captures the notion of "possibility thinking" and supports the argument that imagination cannot and should not be linked only to imagery and visualization (e.g., Medawar's view that central to the scientists' work is "the ability to imagine what the truth might be" does point to a conception of the imagination as the ability to think in terms of possibilities). In science education both the ability to visualize and the ability to think of the possible rather than the actual are considered crucial (see "▶ Visualization and the Learning of Science").

More specifically, imagination is required for the generation of analogies and metaphors, for the construction of thought experiments, and for problem-solving and scientific inquiry (see "▶ Problem Solving in Science Learning"). In the context of science education, with the exception of thought experiments, in which the imagination is stimulated and used regardless of whether those experiments are teacher or student generated (with the creative imagination necessarily present in the process of generation), the above mental activities are not necessarily imaginative. In the case of analogies, helping students understand a science idea (e.g., teaching Coulomb's law as an analogue to Newton's law of universal gravitation) is not as imaginative as is the generation of the analogy, notwithstanding the misconceptions that can arise sometimes from their generation and use. Problem-solving and inquiry can be imaginative activities too but their implementation in a step-by-step fashion, or generally in ways that restrict students' freedom and imagination (e.g., through guidance toward an accepted solution or idea), does not make them imaginative.

As well as the construction and/or use of thought experiments, other imaginative teaching/learning activities are (a) open inquiry, (b) storytelling, and (c) artistic/creative activities (e.g., poetry, drama). All three activities require the stimulation and use of the imagination, through the search of various possibilities (e.g., possible factors that might affect the growth of a plant or the illumination of a room, possible combinations of words to write a poem, possible actions in role playing) and imagery (e.g., Newton under the apple tree, Archimedes in a tub, the trial of Galileo). All three can be meaningful, in the sense that they can encourage engagement with science. Such engagement can be explained by the emotional element (see "▶ Emotion and the Teaching and Learning of Science"), particularly present in storytelling and the artistic/creative activities, thus providing support for the link between emotion and imagination. This link is extremely crucial in the case of young children who role-play and pretend play in order to learn science.

The power of storytelling to stimulate the imagination can be enhanced by encouraging a "romantic understanding" of science. Based on Egan's notion of "romantic understanding," a romantic understanding of science can be defined as a narrative kind of understanding which enables students to become aware of the human context of the science content that they are supposed to learn, by associating, at the same time, such content with heroic human qualities, with the extremes of reality and experience, with a contesting of conventional ideas, and also by experiencing a sense of wonder. This definition of romantic understanding, while different from that of conceptual understanding, nevertheless relates to the content of science in that science is full of extremes, can evoke a sense of wonder, and provides ample opportunities for associating the concepts of science with people and even things that have heroic qualities. Moreover, scientific content can be associated with the contesting of convention if such content is associated with scientists who struggled against conventional and prevailing ideas and beliefs (Hadzigeorgiou et al. 2012).

The notion of "romantic understanding," which can be traced to the romantic conception of science, is in line with the view that the stimulation of the imagination facilitates thinking, and this can take place through strange and unfamiliar situations and also through the elements of paradox, mystery, and wonder. The power of wonder, in particular, to stimulate the imagination and facilitate thinking is central to the so-called "aesthetic" approach to science teaching and learning. This approach is based upon Dewey's notion of "aesthetic" experience, that is, an experience in which reason, imagination, emotion, and action are united (see "▶ Dewey and the Learning of Science").

Although the extent to which science education can stimulate students' imagination has not been specifically researched, evidence from studies on the role of thought experiments, storytelling, romantic understanding and drama in science education (see "▶ Role-Plays and Drama in Science Learning"), and the ways these approaches encourage engagement and learning is quite promising.

Cross-References

- ▶ Analogies in Science
- ▶ Constructivism
- ▶ Dewey and the Learning of Science
- ▶ Emotion and the Teaching and Learning of Science
- ▶ Games for Learning
- ▶ Metaphors for Learning
- ▶ Role-Plays and Drama in Science Learning
- ▶ Visualization and the Learning of Science

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Immersive Environments

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Keywords

Immersive simulations; Virtual reality environments; Virtual worlds

Definition

Immersive environments are digitally mediated learning environments designed to engage users in an artificially created, make-believe "world." Immersive environments may take on a broad range of forms, with affordances for varying degrees of sensory immersion and awareness of the user's physical self or the presence of others. Types of immersive environments extend from massively multiplayer online role-playing games (MMORPGs; e.g., World of Warcraft) and multiuser online virtual worlds (e.g., Second Life) to surround-screen projection-based virtual reality environments (e.g., Cave Automatic Virtual Environments, CAVE).

In MMORPGs, users log into the game from a computer or a game console and assume the role of a character to accomplish the goals of the game – often collaborating and competing with other distributed players who log in from their own computers. Multiuser virtual worlds are similar to MMORPGs in the sense that each user accesses the immersive environment through their own individual computer, acts through an avatar, and interacts with other distributed users who log into the same environment. However, virtual worlds tend not to have game mechanics or goals built into the environment. Rather, users decide for themselves what they wish to accomplish in the virtual world. In the case of both MMORPGs and virtual worlds, the perception of immersion is characterized by cognitive immersion rather than spatial-motor or sensory immersion.

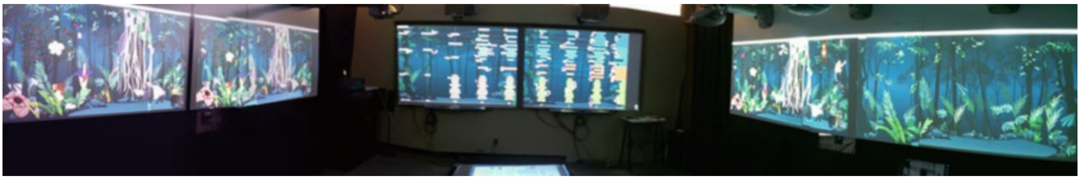
With surround-screen, projection-based virtual reality environments, users are presented with multiple-linked representations, shown on large displays that surround them (e.g., projected on several walls or into the corner of a room). Audio elements may be used to augment users' experiences, enhancing the "immersive" aspect. Characterized by sensory immersion, CAVE environments have been used for training purposes, such as submarine operation and flight simulation.

Immersive Environments for Science Education

For purposes of science education, immersive environments provide students with opportunities to visualize settings that are not otherwise accessible to them and to conduct inquiry within such an environment. In River City, a multiuser online virtual environment, students are immersed in a nineteenth-century city, where they collaborate in distributed teams of three or four to discover why people are getting sick and how they can resolve disease transmission issues (Dede 2009). Using River City, students learn scientific knowledge and inquiry skills.

Another example of immersive environment for learning takes advantage of *both* sensory immersion *and* colocated participants, allowing for collaboration opportunities, to provide a scientific inquiry experience for groups of students in a room-sized immersive environment. EvoRoom, a room-sized immersive simulation of a rainforest ecosystem, allows students an interesting way to investigate evolutionary biology and understand biodiversity. They can walk into the "rainforest," listen to sounds, observe animated plant and animal species, and then "rewind" or "fast-forward" the room through its evolutionary development over 200 million years. Collaborative inquiry activities are designed to guide or complement students' interaction with immersive simulations. Depending on the size of the room used for the immersive simulation, several small groups of students work together on different inquiry tasks. Technology supports, as accessed with tablet computers or other mobile devices, are designed to provide further support for students during the inquiry process (Lui and Slotta 2014; Fig. 1).

Taken together, immersive learning environments such as River City (i.e., a game-like environment where students are cognitively engaged) and EvoRoom (a room-sized simulation in which students are immersed physically and cognitively) offer a promising avenue for science education. New technologies, including projectors, touch screens, and computer vision and sensing



Immersive Environments, Fig. 1 EvoRoom, an immersive simulation for teaching biodiversity and evolution, which consists six projected displays (three on each side) and two interactive whiteboards (*middle*)

(e.g., Microsoft Kinect), are making it easier to develop powerful new ways for students to interact with materials and peers in a variety of learning environments.

Cross-References

- ▶ Online Inquiry Environments
- ▶ Simulation Environments
- ▶ Technology for Science Education: Research

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Immersive Exhibitions

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The immersive exhibition is a specialized exhibition genre in museums, which creates the illusion of time and place by representing key characteristics of a reference world and by integrating the visitor in this three-dimensionally reconstructed world (Mortensen 2010). A successful representation of the reference world depends on three criteria: whether the exhibition is staged as a coherent whole with all the displayed objects supporting the representation, whether the visitor is integrated as a component of the exhibition, and whether the content and message of the exhibition become dramatized as a result of the visitor's interaction with the exhibit.

Immersive Exhibition Types

Immersive exhibitions may be classified by how they represent their reference world. An immersive exhibition that is based on an *exogenous* logic reconstitutes a reference world that is real or fictional and reconstitutes this reference world as authentically as possible. This type of immersive exhibition is therefore based on a model of *reconstitution*. Examples are life-sized environments such as a forest clearing or Sherlock Holmes' study, which incorporate authentic objects such as taxidermied animals or real furniture. The layout of such exhibitions is thus governed by a logic that exists outside of (exogenously to) the exhibit, namely, the logic which characterizes the reference world (Montpetit 1996).

An immersive exhibition that is based on an *endogenous* logic is an exhibition that refers to a world that neither exists nor has existed. The world represented in the exhibition is created ad hoc to serve the needs of the exhibition objectives and follows only the rules and logic which it itself generates (which are endogenous to it). This type of immersive exhibition is therefore based on a model of *creation* (Montpetit 1996). An example could be a "sensory tunnel" in which the intent is to let the visitor explore their five senses one by one as they proceed through a tunnel.

The layout of such an exhibition is governed by the objective of providing visitors with an experience of their five senses and does not correspond to any existing reference world.

Finally, an immersive exhibition that employs a combination of exogenous and endogenous logics is an exhibition that utilizes interpretation. This is often the case when the knowledge to be exhibited is not associated with a representable human-scale realm, or the significant experiences of the reference world are abstract. Interpretative immersion exhibitions thus combine the exogenous logic of an existing reference world with the endogenous logic generated by their own setting-in-scene. This type of immersive exhibition is therefore based on a model of *interpretation* (Montpetit 1996). An example could be a walk-through scale model of the human digestive tract. The morphology of such an exhibition would be based on the exogenous logic of an existing reference world (the human digestive tract) interpreted by exhibition engineers to create an analogical representation according to an endogenous logic.

Immersive exhibitions that are based on an endogenous logic diverge from the basic analogy of resemblance that characterizes *reconstitution* immersive exhibitions. Instead of physically resembling their reference worlds, *creation* or *interpretation* exhibitions must rely on an indicative or symbolic relationship with their reference worlds. Common to all types of immersion exhibitions, however, is the fact that they consist of self-contained systems of meaning and symbols designed by the exhibition engineers for the purpose of creating a *microculture* for the museum visitor to enter into (Mortensen 2010).

The Role of the Visitor

Immersive exhibitions usually specify a role for the visitor. Depending on the model of representation and the exhibit's subject matter, the intended role of the visitor may be more or less integrated in the exhibit. For example, an immersion exhibition reconstituting an African rain forest with a pathway may provide a setting and ambience in which visitors can immerse themselves, playing the role of themselves, i.e., that of a person walking along a rain forest path. A stronger degree of immersion may be observed in exhibitions which assign the visitor a specific character to play, for instance, that of an animal in its habitat. Finally, exhibitions that utilize virtual reality can allow visitors to act on the represented world, modifying it in real time. In sum, the degree of visitor integration in an immersion exhibition falls within the range from *setting and ambience* to *role play* and finally to *real-time modification of environment* (Belaën 2003; Mortensen 2010).

Visitor Reactions to Immersive Exhibitions

How well an immersive exhibition disseminates its meaning and message depends on how well the visitor recognizes and accepts the represented world and the role assigned to them. This is an undertaking which requires a certain suspension of reality, and not all museum visitors are willing and/or able to do this. Common visitor reactions to immersion exhibitions range from *resonance*, where visitors willingly surrender themselves to the immersion premise, to *distance*, where the visitor considers the staging of the content to be disproportionate to the content itself, and finally to *rejection*, where the visitor figuratively and sometimes literally fails to enter the immersive environment (Belaën 2003; Mortensen 2010).

Cross-References

- ► Interactive Exhibits
- ► Visitor Studies

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Implemented Curriculum

► Curriculum

Indigenous and Minority Teacher Education

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Keywords

Indigenous; Minority; Teacher education

Main Text

Indigenous and minority science teacher preparation programs target specific cultural populations who are underrepresented in the mainstream science teacher population. There are a variety of approaches to indigenous and minority science teacher education: programs that target accessibility, those that focus on cross-cultural pedagogy, and programs that can be characterized as transformative.

Access-Oriented Science Teacher Education

Accessibility-focused science teacher education programs provide supports to prospective indigenous and minority education students. Access programs recognize that there is not an even playing field when trying to gain entry into and remain in post-secondary education programs and try to rectify the underrepresentation of indigenous and minority science teachers by providing a variety of supports. Examples of these programs are the University of Manitoba Access Program (targets minority and indigenous students for several degree programs including primary and secondary teacher education), the Aboriginal Teacher Education Programs at Queen's University, Kingston, University of Alberta, and the University of Saskatchewan. Financial support is often a part of access-oriented programs, but academic and social supports are viewed as important factors for success. Some examples of social supports in these programs are personal counseling to deal with home sickness and family issues, help with the transition to an urban center, assistance with locating day cares or other family resources, and help connecting to cultural resources in an urban setting (such as elders, peers, and cultural programming). Academic supports may also be a part of the access-oriented science teacher preparation programs. Academic supports could include tutoring, upgrading, and study skills development. In access-oriented programs, indigenous and minority students attend classes in the mainstream science teacher education program. In other words they are external to the actual education program and provide supports to students from the outside. The programs have been very successful in Canada in increasing the representation of indigenous and minority teachers in mainstream schools, but primarily at the primary level and rarely students graduate as science specialists.

Indigenous and Minority Science Teacher Education That Includes Culturally Relevant Approaches

There are some teacher education programs that are more culturally based. Usually these programs are separate from the mainstream but affiliated with a post-secondary institution. Some programs are community based which makes it easier to incorporate local knowledge and culture into all aspects of the teacher education program. Examples of these programs are the Bachelor of Teaching (Anangu Education) at the University of South Australia and the Northern Teacher Education Program (NORTEP) based out of the University of Saskatchewan. However, the process by which cultural knowledge and Western science are incorporated into teacher preparation varies. Some programs focus on incorporating cultural into instruction, others on developing teachers as border crossers to help students navigate their worldviews and the views of science, and still other programs embed indigenous language into science instruction.

Some examples of science teacher preparation programs that incorporate culture into instruction are the Rekindling Traditions project (http://www.usask.ca/education/ccstu/welcome.html) and Malama I Ka ʻAina (http://malama.hawaii.edu/Chinn). Both of these projects were for practicing science teachers. Rekindling Traditions was a project led by Glen Aikenhead, which sought to lead science teachers through a process in order to produce culturally relevant science units for use in science classrooms. Aikenhead used a border-crossing approach to science teacher education in this project. Aikenhead (2006) describes an effective culture-brokering teacher as one who “clearly identifies the border to be crossed, guides students back and forth across that border, and helps them negotiate cultural conflicts that may arise” (p. 235). Chinn’s project worked with science teachers to develop teaching approaches that emphasized the importance of place (Chinn 2007).

Transformative Science Teacher Education

Some educators have argued that cultural understandings are transmitted through language, and the only way to develop a transformative science program that incorporates indigenous understanding is if it is taught within the local language and culture. Pihama et al. (2002) developed a theoretical framework that positions Kura Kaupapa Māori as transformative praxis. Kaupapa MāoriTheory evolved out of transformative praxis in New Zealand education driven by the incorporation of Māori theoretical and methodological preferences and practices, i.e., being and acting Māori (Sexton 2011). McKinley (2005) has argued that “one of the main ways in which Indigenous knowledge systems can survive and thrive is through the establishment of programs taught through Indigenous languages so that a dialectal relationship between language and knowledge is established that continues to act as the wellspring” (p. 227). This fact emphasized a need for a cross-cultural approach to science teaching that includes language instruction and the transmission of indigenous knowledge in its language of origin. This has been the approach in Māori science education, a model with demonstrable successful outcomes. An example of this is Te Wānanga Takiura that offers a bachelor’s degree qualification in Kura Kaupapa Māori teaching. Te Wānanga is a tertiary education program that embraces a Māori worldview, values, and aspirations.

Cross-References

- ▶ Culturally-Relevant Pedagogy
- ▶ Culture and Science Learning
- ▶ Indigenous and Minority Teacher Education
- ▶ Indigenous Knowledge
- ▶ Indigenous Knowledge Systems and the Nature of Science
- ▶ Indigenous Students
- ▶ Language and Learning Science
- ▶ Teacher Preparation and Indigenous Students

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Indigenous Knowledge

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Keywords

Indigenous; Science; Science Education in the Non-West; Values

As indicated by the entry title, this piece of work is based on *indigenous knowledge (IK)*. In an attempt to explain or define it, some related concepts such as *indigenous* and *indigenous people* are explained. It is important to define these concepts separately before combining them. To make indigenous knowledge more explicit, an example in the form of a picture from a real life situation is provided.

There are various definitions of the concept *indigenous*. The term refers to plants, animals, or people that naturally belong to a particular place. One can further define it as native – not introduced directly or indirectly according to historical record or scientific analysis into a particular land or region or environment from the outside but indigenous or natural to a region or place. When applied to denote human beings, the term *indigenous* is associated with people originating or developing naturally in a particular land or region or environment. It is thus the term used to describe people who are the original inhabitants of a particular geographical area.

In keeping with the meaning of *indigenous* above, it can be deduced that *indigenous people* are the custodians of indigenous knowledge. However, it should be noted that the definition of indigenous people is not always clear. This definition is complicated by the fact that this term includes culture, identity, language, tradition, faith, and belief. In this case the term *indigenous people* refers to people naturally originating in a particular country/region/place (or aboriginal to a place), namely, natives or simply Blacks in the case of South Africa. Some people have been born in South Africa and/or their grand-grandparents were also born in this country. Unfortunately, no matter how patriotic and loyal they may be, they cannot be referred to as the indigenous people of South Africa, but they do qualify to be the citizens of South Africa. The principles of Ubuntu (caring, tolerance, respect, communal, etc.) by which indigenous Africans live allow them space to be part of the South African community. This also means that all Africans (Blacks) who found themselves in India cannot claim to be indigenous people of India even though some of them have been born in that country. This is due to the origin of their forefathers being (South) Africa from a diasporan perspective.

The term "indigenous people" is closely related to indigenous knowledge. Indigenous knowledge implies knowledge that *originates* and is exclusive to an area without borrowing from or being influenced by knowledge from outside it. The literature regarding indigenous knowledge systems does not lead to one single definition of the term but rather to a description thereof, which in itself must indicate the problem with understanding what the term really means. The concept is referred to in different forms that could include terms like indigenous knowledge, indigenous technical knowledge, local knowledge, folk knowledge, traditional knowledge, traditional environmental (or ecological) knowledge, people's science, and more.

Indigenous knowledge can be broadly defined as the knowledge that an indigenous (local) community accumulates over generations of living in a particular environment. This definition

Indigenous Knowledge, Fig. 1 Indigenous knowledge applied in the traditional medical practice

encompasses all forms of knowledge – technologies, know-how skills, practices, and beliefs – that enable the community to achieve stable livelihoods in their environment. Indigenous knowledge is the homegrown and local knowledge – knowledge that is unique to a given culture or society. It is the basis for local-level decision making in agriculture, health care, food preparation, education, natural-resource management, and a host of other activities, and it is more evident in rural communities which have not adopted more of the urban lifestyles typical of the western culture.

Indigenous knowledge is the information base for a society, which facilitates communication and decision making. Indigenous information systems are dynamic and are continually influenced by internal creativity and experimentation as well as by contact with external systems. It forms livelihoods of indigenous people who depend almost entirely on specific skills and knowledge essential for their survival. Accordingly, for the development process, as indicated above, indigenous knowledge is of particular relevance for the following sectors and strategies: *agriculture, animal husbandry, and ethnic veterinary medicine (refer to the picture below), use and management of natural resources, primary health care, preventive medicine and psychosocial care, saving and lending, community development, and poverty alleviation.*

Indigenous knowledge is relevant on three levels for the development process. Firstly, it is most important for the local community in which the bearers of such knowledge live and produce. Secondly, development agents (CBOs, NGOs, governments, donors, local leaders, and private sector initiatives) need to recognize, value, and appreciate it in their interaction with the local communities. Before incorporating it in their approaches, they need to understand it – and critically validate it against the usefulness for their intended objectives. Lastly, indigenous knowledge forms part of the global knowledge. In this context, it has a value and relevance in itself. Indigenous knowledge can be preserved, transferred, or adopted and adapted elsewhere.

Indigenous knowledge is not a system of knowledge that is in opposition to a general so-called western scientific knowledge system and should not be compared to such, but evaluated on its own merit. At the same time indigenous knowledge systems cannot be interpreted or evaluated from a Eurocentric view alone. They have to be seen and understood within their own cultural contexts. Indigenous knowledge systems are also not static and place bound; they are systems of local knowledge that warrant integration into the mainstream of knowledge.

Indigenous knowledge systems are a key element in the development of poor communities and provide “culture-fit” problem-solving strategies for a diversity of situations, for instance, in primary health care, preventive medicine, and veterinary medicine. Traditional herbs, such as displayed in Fig. 1 above, play an important role in formal and informal medical systems in South Africa.

Cross-References

- ▶ Indigenous Knowledge Systems and the Nature of Science
- ▶ Indigenous Medicinal Knowledge
- ▶ Indigenous Technology
- ▶ Values and Indigenous Knowledge

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Indigenous Knowledge Systems and the Nature of Science

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Keywords

Cultural contexts; Knowledge; Science

Chalmers (1980) poses a fundamental question in the title of his book, *What Is This Thing Called Science?* Philosophers of science and science educators for decades have attempted to create one clear, all-encompassing definition of science. However, these two groups have rarely developed definitions on which they both agree. The complexity involved in establishing one agreed definition of science is in part due to the difference in the purpose of the definition. Philosophers look for a definition of science that will provide an accurate depiction of the process of science. This definition serves as a guideline to those in the pursuit of scientific inquiry, the scientist, and the production of new scientific knowledge. In other words, philosophers develop a functional definition of science.

On the other hand, science educators attempt to obtain a definition of science that will provide direction to those in the pursuit of learning already preestablished scientific knowledge. Thus, the definition of science is a pragmatic one, used to design curriculum, develop teaching strategies, and encourage the understanding of scientific knowledge. The motives of each discipline make the creation of one broadly adequate and acceptable definition of science virtually impossible.

In science education one definition of Western science, also referred to as Western modern science or Eurocentric science, is “the pursuit of knowledge and understanding of the natural and social world following a systematic methodology based on evidence” (British Science Council 2009). This definition seems to be one in which both science educators and philosophers of science agree. The definition of the nature of science varies from curricula and policy objective statements; however, in general it refers to the “. . .values and assumptions inherent to the development of scientific knowledge” (Lederman 1992, p. 331).

Many science educators describe the nature of science by identifying its various presuppositions or tenets. This process has led to an inventory of tenets which may include nature is knowable, science is contextual, science is predictable, scientific knowledge is dynamic, scientific knowledge is generalizable, science is linear, science subscribes to Cartesian dualism, science is reductionist, science is anthropocentric, and science can represent reality. Research programs in science education that focus on the nature of science have looked at the public's understanding of science, science teacher's understanding of science, and student's understanding of science using these tenets as a guide for evaluation.

In the new millennium, scientists have been urged by some international history and philosophy societies to learn from systems of indigenous knowledge. These indigenous traditions – which have also been labeled as local, traditional, or folk knowledge – developed as adaptations to their environments conditioned by their specific cultural contexts. The International Council for Science (ICSU) created a picture of indigenous knowledge that describes it as:

> A cumulative body of knowledge, know-how, practices and representations maintained and developed by peoples with extended histories of interaction with the natural environment. These sophisticated sets of understandings, interpretations and meanings are part and parcel of a cultural complex that encompasses language, naming and classification systems, resource use practices, ritual, spirituality and worldview. (2002, p. 3)

Many authors have tried to identify the fundamental attributes of indigenous knowledge. One such list created by Aikenhead and Michell (2011) includes the following attributes for indigenous knowledge: place-based, holistic, relational, dynamic, systematically empirical, based on cyclical time, rational, and spiritual. Research programs in science education that focus on indigenous knowledge and the nature of science tend to concentrate on the process of incorporating indigenous knowledge into science instruction and the processes of learning science in a cultural context.

Cross-References

- ▶ Indigenous and Minority Teacher Education
- ▶ Indigenous Knowledge
- ▶ NOS: Cultural Perspectives
- ▶ Values and Indigenous Knowledge

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Indigenous Medicinal Knowledge

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Indigenous medicinal knowledge (IMK) refers to the sum total of all knowledge and practices whether explicable or not, used in diagnosis, prevention, and elimination of physical, mental, and social imbalance and, relying exclusively on practical experience and observation, handed down from generation to generation whether verbally or in writing (WHO Traditional Indigenous Medical Programme 2008; see Soewu, Adekanola (2011)). IMK's diverse methods include physical, mental, and spiritual therapies, usually strongly influenced by the culture and beliefs dominant in a particular community.

Balasubramanian (1997) notes that IMK serves the health needs of the vast majority of people in developing countries where persistent poverty and marginalization limits access to Western medicine. IMK helps to translate natural resources into products and services of unique and organic value, improves nutritional levels by utilizing local food materials from the immediate environment, and improves health and income levels of indigenous communities for more sustainable livelihoods. Moreover, many herbal plants known to IMK have become essential raw materials for making pharmaceutical products; hence, there is an important link between IMK and the developed world (Fabricant, Farnsworth 2001).

IMK can be important in science education as a way for indigenous schools to link science with local knowledge and for students in the developing world to learn more about how the resources of the developing world contribute to scientific knowledge. IMK and science education jointly can help to translate natural resources into products and services of unique and organic value, improve nutritional levels by utilizing local food materials from the immediate environment, and upgrade the health and income levels of indigenous communities by accessing them to quality and affordable herbal medicines available in their respective localities – for community-wide, sustainable livelihoods (Nelson-Harrison et al. 2002).

Cross-References

- ▶ Indigenous Knowledge
- ▶ Indigenous Knowledge Systems and the Nature of Science
- ▶ Indigenous Technology
- ▶ Values and Indigenous Knowledge

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Indigenous Students

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Keywords

Aboriginal students; Alaska Native students; American Indian students; First Nations students; Native Hawaiian students; Native students

The term Indigenous has come to identify those groups of people whose cultural, political, and ancestral genealogy and identity are connected to and have historical rights in particular territories. Many Indigenous people around the world have experienced colonization, attempted genocides, or formations of contemporary nation states that have bearing on their own sovereignty and self-determination. There are estimated more than 350 million Indigenous peoples across the earth. Indigenous peoples have, to varying degrees, maintained, won, or struggled for cultural and political distinction from mainstream culture and political system of nation states within the border of which many indigenous many communities are now enclosed. However, there are many Indigenous communities who do not have sovereign recognition by nation states. It is important to note that this does not mean these communities are not Indigenous; rather it is an indicator of the ongoing tensions and struggles over territory and cultural and political self-determination. Indigenous students are the children and adults with communal and genealogical ties to Indigenous communities – that is, students who themselves and/or their families are engaged in the communal and cultural life of Indigenous peoples. Many Indigenous peoples have rich knowledge systems, traditions, and traditional knowledge that are a vibrant part of community life. For many Indigenous peoples, their knowledge systems are intimately connected to their lands. Indigenous communities have been impacted by colonization in a myriad of ways, one of which is through generations of intermarriage, forced removal from homelands to new land bases, and a variety of assimilation and relocation policies that encouraged and demanded separation from tribal communities into urban locations. For some, these imposed separations were not permanent: many relocation survivors have created rich and vibrant contemporary Indigenous communities in ceded urban territories. However, these intertribal communities increase the complexity in understanding Indigenous children because many are mixed race and multi-tribal with diverse connections and participation in their cultural practices.

Cross-References

- ▶ Indigenous Knowledge
- ▶ Values and Indigenous Knowledge

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Indigenous Technology

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Understanding "indigenous technology" begins with defining *indigenous*. The possible definitions are many. The term is used in reference to plants, animals, or people that naturally belong to a particular place (Hornby 1998, p. 606). It can be defined as "native," as in something not introduced directly or indirectly according to historical record or scientific analysis into a particular land or region or environment from the outside (Kim and Berry (1993, p. 2). *Indigenous* is associated with people originating or developing naturally in a particular land, region, or environment (Kim and Berry 1993, p. 2). *Indigenous* is a term used to describe people *who* are *the* original *inhabitants* of a particular geographical area (Pollock 1995, p. 21).

Indigenous people are the custodians of indigenous technology. The definition of indigenous people is not always clear (Psacharopoulos and Partrinos 1994, p. 21) as it is complicated by the fact that the term *indigenous people* includes culture, identity, language, tradition, faith, and belief (Gumbo 2001). However, indigenous people may be thought of as those people naturally originating in a particular country or region or natives. There may also be specific names such as Blacks in the case of South Africa. To be indigenous, people must be in their indigenous environment. Thus, for example, Black Africans even if born in India cannot claim to be indigenous people of India.

With respect to *technology*, technology refers to the totality of the means employed to provide objects necessary for human sustenance and comfort (Arnoldi, Geary and Hardin 1996, p. 31). It is the science of construction (Gillet 1973, p. 2). This definition can be extended to include the use of tools that are in turn the products of the same technology. Technology is the application of scientific and other organized knowledge to practical tasks by hierarchically ordered systems that involve people and machines (Naughton 1981, p. 8). Others define technology as the know-how and creative process that may use tools, resources, and systems to solve problems to enhance control over the natural and man-made environment in an endeavor to improve human conditions (Treagust and Mather 1990, p. 53). It is regarded as human knowledge applied to the solution of existing practical problems (Waks 1995, p. 2.2). Technology can therefore be defined as a disciplined process where human knowledge, skills, and resources are used to construct tools in order to find a solution to existing practical problems by investigating, designing, developing, and evaluating products, processes, and systems.

Taken together, *indigenous technology* refers to the technological knowledge, skills, and resources transmitted or handed down from the past indigenous people to the present ones to meet their needs and wants by means of investigating, designing, developing, and evaluating products, processes, and systems with an intention of solving the practical problems. Indigenous technology is used by the native inhabitants of a country or region and it constitutes an important part of its cultural heritage.

Characteristically, indigenous technologies:

- Are recognized as animate, imbued with the breath of life and they live in form and function.
- Emerge from the implicate order to reflect the art of skillful living. Indigenous technologies are pragmatic. It is responsive and responsible to the ecology in which it lives.
- Attract the learning spirit(s) and provide a learning ecology that supports the revitalization and transformation of awareness and knowledge.
- Are intended to enhance the ability to maintain and renew balance and harmony within a multidimensional environment.
- Are created within a sensory environment that builds on our sense of relationship, meaning, balance, feeling, memory, and place as well as sight, sound, smell, taste, and touch.
- Seeks to engage and evoke significant knowledge and experiences reflective of the indigenous world through meaningful interactions.
- Have the obligation to come into existence, to be used, and to transform within an ethical space that is responsible to life in all its forms.
- Have intrinsic value because we know their ancestry and what their place is in our world.

The following photos show examples of indigenous technology in South African. These technologies address such needs as shelter, food, defense, and clothing.

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- ► Indigenous Knowledge
- ► Values and Indigenous Knowledge

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Industry Visits

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Keywords

Factories; Manufacturing; Outside learning; Site visits

Industry visits are a valuable component in the educational landscape. These visits take various forms and can involve teachers and students from both elementary and high schools. Teachers are keen to participate in visits when the links to the curriculum are clear and explicit, but often find it difficult to make time to initiate links with industry or to see and appreciate the wide range of curriculum-relevant activities that a site visit can offer (Parvin and Stephenson 2004). Industry wishes to foster relationships with local schools, but can find it difficult to know what to offer, beyond sponsoring a football team or buying books and equipment for schools. Organizations that broker better relationships between schools and industry are important to build and sustain partnerships. Organizations in the UK include *CIEC Promoting Science* (www.ciec.org.uk) and *STEMNET* (www.stemnet.org.uk). As well as fostering relationships, these organizations create freely available materials demonstrating relationships between the science, technology, and mathematics curricula and their applications in the "real world." These materials include practical science experiments which are grounded in industrial storylines and which address important scientific concepts, skills, and knowledge. These activities can be carried out in the classroom, in after-school science clubs, to prepare for a visit and to develop the storyline further. An example of these activities can be found at www.scienceofhealthyskin.org.uk, which is aimed at elementary teachers for use with 9- to 11-year-old students. The resource encourages links with companies that produce active ingredients in sun creams, which use lanolin in cosmetic products, and in which foaming is an important criterion of product design.

To ensure effectiveness of industry visits, brokerage organizations train industry personnel and teachers so that they can work together. During training, industry personnel discover which areas of their site might have the greatest impact on students and highest relevance to the curriculum. For example, they learn how to engage students in practical activities or demonstrations in their site's laboratories and help show the vast scale and degree of automation of production, while ensuring that students meet a range of scientists and engineers engaged in design, production, management, and marketing. This allows students to appreciate the wide range of careers to which studying science can lead. Meeting the "real person" face-to-face in the industrial setting has a much higher impact on students than watching a video of that person at work. A particularly important aspect for girls is seeing women carrying out scientific and technical roles, thus providing positive role models to which they can aspire.

Effective site visits can have a long-lasting impact on students, who can be switched on to considering studying science beyond compulsory school age and potentially taking up a career in industry. Even if students do not consider such career paths, effective industry visits help them to develop a more balanced and authentic perspective of industry, beyond the commonly perceived images of chimneys, pipes, and pollution, as a 5-year study of students' ideas of industry has shown (Evans et al. 2004).

Cross-References

- ▶ Learning Science in Informal Contexts
- ▶ School-Community Projects/Programs
- ▶ Scientist-School Interactions

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Information Processing and the Learning of Science

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In the second half of the twentieth century, cognitivism replaced behaviorism as the dominant paradigm in psychology. Where behaviorism avoided speculation about unobservable processes such as thinking and reflection and concepts such as understanding, mind, and will, cognitive psychology postulated models of mental processes that are involved in learning and problem solving. These models of information processing derived from digital computers, which became common at this time. The brain was pictured as a machine, like the computer, which accepted input via the senses, processed it into meaningful form, stored it, and was able to retrieve it on demand.

The classic model was of serial processing, as in the first Turing machines, where each incoming bit of information is dealt with by a central processing unit following a predetermined algorithm with the outcome placed in its turn in a memory slot, in fixed sequence. The model had shortcomings: serial processing is too slow to explain the brain's rapidity in managing complex performances; it is brittle, in that damage to any one step destroys the whole process, while the brain is robust, able to fill in gaps in input and to recognize and remedy minor errors; it is inflexible, following a rigid sequence of operations and so cannot cope with novel or messy input, something that the brain does quite well. In an attempt to reduce these shortcomings, parallel processing which handles multiple tasks simultaneously, a feature of later computers, became part of the model. Nevertheless, the model remains a model, of a machine, imperfectly matching the subtlety and complexity of the brain. As has been pointed out frequently, computers cope easily with tasks that the brain finds challenging, while the brain readily solves problems that defeat even the most powerful computers. Therefore, application of information processing to the subtleties and complexities of teaching any subject, and perhaps especially of science in its own complex depiction of the natural world, will not provide a comprehensive guide to classroom action. That does not make the model totally useless, however, just as the inabilities of the wave and particle models to explain all the phenomena of light do not make them useless in physics. There are aspects of the model that can inform teaching.

In its basic form, information processing depicts learning as a sequence of operations: selection, translation, storage, and retrieval White (1998).

Selection. As do all living organisms, humans react to stimuli coming from their surroundings. They are not, however, aware of every single stimulus. They attend to things that they judge important. While some of this judgment is instinctive, as in reaction to fast-moving objects near the head, much depends on previous learning. People observe stimuli that seem important to them at the time and ignore the rest. In this they differ from a computer, which accepts all of the input it receives. Thus, learning is not a linear process, but an interactive or recursive one.

Teachers manage students' selection by pointing out the features that matter of an object or event, such as the parts of a flower or a chemical reaction. Their success depends on whether the students accept the teacher's assertion that these features are worth attending to, and that acceptance in turn depends on a complex mix of the student's needs and purposes and on existence or absence of competing stimuli (such as behavior of other students). In other words, the students' motivations for learning, liking for science and for individual topics within it, and relation with the teacher affect what they attend to. So does their physical state: as teachers soon realize, tiredness or illness inhibit alertness and consequently selection.

Translation. According to the information processing model, learners translate observed stimuli into a meaningful form, initially held in a short-term memory buffer of limited capacity. In early childhood children acquire many skills of translation, rapidly increasing their capacity to make sense of their environment. Translation remains important in later learning, where students might need guidance to understand what they are seeing or are told. For instance, differentiating a landscape into features such as horsts, peneplains, and faults has to be learned. An important consequence is that the experienced and knowledgeable observer sees a smaller number of units than the tyro, who can be overwhelmed by the detail. If too much information comes in, the short-term buffer is overloaded, and much is lost. Teachers therefore need to teach students how to see, how to form the information into a smaller number of larger meaningful units. This needs care, for students might come to only ever see what the teacher directs them to see, and so might miss curious elements.

Information that has been processed into meaning can follow two paths. In one, it is erased by newer incoming stimuli and immediately forgotten. In the other, it remains in working memory until it is either processed further into long-term memory or is lost. Thus, people can recall events for some days, but unless the event is linked with existing knowledge for some reason, after a few days or even shorter the memory is lost.

Storage. Some of what is translated is stored as knowledge in long-term memory. Theorists have proposed various divisions of this knowledge, such as semantic versus episodic, propositional versus procedural, declarative versus non-declarative, words and images, propositions, algorithms, images, episodes, and strings. These divisions may be important in science education, since different forms of knowledge may be learned differently and therefore need to be taught in different ways; because individual learners may have idiosyncratic preferences and vary in the ease with which they acquire each form; and because different mixes of forms will result in different qualities of understanding.

Storage in long-term memory is a function of individual preference of the learner and of actions of the teacher: what the learner is interested in and perceives as meeting a need and what the teacher emphasizes as important or makes interesting. Storage can be as unorganized, unconnected elements, or as a highly interlinked network. Level of understanding is a consequence of extent of linking. Effective teaching is likely to involve making clear connections between individual pieces of knowledge within a topic and across topics. Thus, a student who perceives commonalities between gravitational, electric, and magnetic fields will have better understanding than one for whom these are unrelated topics.

Retrieval. Models of information processing do not prohibit reorganization of knowledge subsequent to its acquisition, through reflection that creates perception of new links, but essentially they present a static notion of knowledge: it is acquired and remains in long-term memory more or less in its original form, whereas human memory is more dynamic. Where in a computer what is retrieved from a memory cell is what is stored there, in humans retrieval involves reconstruction, in which factors such as context affect the recall. In one context, one might recall knowledge of motion as Aristotelian and in another as Galilean/Newtonian or a tomato as a fruit in a biology class but as a vegetable in the kitchen. The influence of context on reconstruction is largely responsible for the alternative conceptions that became the focus of much research in science education in the last third of the twentieth century. Students who learned a scientist's explanation for a phenomenon often maintained a non-science explanation as well, offering one explanation in one context and the other in another.

Metalearning. The notion of metalearning came later than models of information processing but fits readily with them. Metalearning refers to knowledge of processes of learning, awareness of their application, and ability and willingness to control them. Thus, metalearning can refer to conscious and deliberate selection, translation, storage, and retrieval (Brown 1987; Georghiades 2004).

While metalearning is fundamental to quality of learning in all subjects, it is particularly important in science education, which presents students with explanations of the complex natural world that may be at odds with beliefs that they have acquired through folk lore or through unguided experiences. Resolution of such differences is unlikely without conscious management of learning processes. Training students in metalearning is an advanced teaching skill. For accounts of practical programs, see Baird and Northfield (1992) and Adey and Shayer (1994).

Cross-References

- ▶ Cognitive Acceleration
- ▶ Memory and Science Learning
- ▶ Metacognition and Science Learning

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Inquiry, Assessment of the Ability to

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Keywords

Formative; Inquiry skills; Reliability; Summative; Test; Validity

To inquire (also spelled enquire) is a term used in both daily life and in education, meaning to investigate or seek information to answer questions. In education, the ability to inquire is relevant in many subject domains, such as history, geography, the arts, as well as science, mathematics, technology, and engineering, when questions are raised, and the skills of generating, collecting, and using data are used in developing understanding. In science, understanding of the natural and made world is developed through using skills such as raising questions, collecting data, reasoning and reviewing evidence in the light of what is already known, drawing conclusions, and communicating results. Although an inquiry is generally initiated by a question, in education the value of the activity is more than finding an answer; it contributes both to the understanding of the "big ideas" that apply beyond the specific event or phenomenon being studied and to the development of skills that enable further learning.

Science Inquiry Skills

Skills used in scientific investigation and inquiry are identified in slightly different ways in different curricula and standards statements. However, they have much in common and generally include the following:

- Asking questions
- Generating hypotheses or possible answers
- Making predictions
- Planning and carrying out investigations
- Analyzing and interpreting data
- Constructing explanations based on evidence
- Evaluating and communicating findings

The assessment of the ability to use these skills has to take account of three key points. First is that students have to be using, or given the opportunity to use, the skill in order for their ability to be assessed. Second is that any skill has to be used in relation to some subject matter: there can be no "content-free" skill. Questions and tasks have to be asked about something, observations are made about particular objects and events, and investigations are planned to answer questions about particular phenomena. There has to be some subject matter involved when skills are used and what this is makes a difference to whether skills are used. For example, a student may be able to plan an appropriate investigation about a situation where he/she has some knowledge of what are likely to be the variables to control, but fails to do this if the subject matter is unfamiliar. This has important consequences for assessment. The subject of a particular task or test item is just one of a potentially large number of alternative subjects. Practice bears out the possibility that a student's result would be different if an alternative subject had been chosen; thus there is a variation in the results associated with the choice – an unavoidable error – since no two tasks with different subject matter or contexts can be exactly equivalent. To emphasize the role of content knowledge, the National Research Council adopted the term "practices" in place of "skills" (NRC 2012, p. 30). However, given the acknowledgment that some knowledge of the content is always involved, it does not seem necessary to abandon the use of this familiar term.

A third key point follows from the general recognition that assessment should be aligned with the educational goals and student learning objectives to be achieved through the curriculum content and pedagogy. This alignment is essential for validity of the assessment. Following the conception of the validity of an assessment as the extent to which there is evidence supporting inferences drawn from the results (Messick 1989), the validity of an assessment of ability to inquire depends on evidence that, when being assessed, students are engaged in activity that involves the use of some or all of the inquiry skills. This would not be the case, for instance, if a student simply recalls the answer to a question rather than using skills to work it out. Furthermore, the processes being used by the students should reflect the view of learning underlying inquiry-based pedagogy. This view is that students are active agents in their learning, bringing their existing experience and ideas to bear in pursuing questions or addressing problems that engage their attention and thinking. By collecting information for themselves, they have the evidence of what works and what does not work in helping them to make sense of different aspects of the world around. In addition, there is emphasis on individuals making sense of experience with the help of others, indicating a sociocultural constructivist perspective on learning and underlining the value of collaboration, communication, dialogue, and argumentation.

Assessment Purposes

Assessment of students' learning involves generating, collecting, and interpreting evidence for some purpose. Three main purposes of assessment are commonly identified: assessment to assist learning (formative assessment), assessment of individual students' achievement (summative assessment), and assessment to evaluate programs (Pellegrino et al. 2001). The focus here is on the first two purposes, which have a direct impact on individual students.

Formative Assessment of the Ability to Inquire

The practice of formative assessment, through teachers and students collecting data about learning as it takes place and feeding back information to regulate teaching and learning, is clearly aligned with the goals and practices of inquiry-based learning. It also supports student agency in learning through promoting self-assessment and participation in decisions about next steps, helping students to take some responsibility for their learning at school and beyond. Thus formative assessment fosters inquiry-based learning through supporting students in gathering and interpreting evidence in a manner that develops their understanding.

Gathering and Interpreting Data

Formative assessment is essentially in the hands of teachers who gather evidence students' skills and understanding by:

- Using questions designed to elicit students' thinking and reasons for their actions
- Promoting classroom dialogue
- Reviewing students' notebooks

For this purpose, teachers' questions are best framed to show interest in the students' thinking ("What are your ideas about what's happening here?") and to encourage the use of inquiry skills ("How are you going to test that idea?" "What will you do with these results?"). Promoting collaboration and dialogue among students not only fosters shared thinking but provides opportunity for teachers to observe how students interact and to listen to what they are paying attention to and how they are using words. The contributions and thinking of individual students can be gleaned from review of their notebooks.

However, whether the assessment is formative depends on how the evidence is interpreted and used. In formative assessment, interpretation is in terms of progress toward the specific goals of the lesson or unit of work. Both teacher and students should be aware of these goals, which determine the kind of evidence required to judge students' progress. Through discussion with students, questioning that elicits their understanding of what they are doing and listening to how they explain what they are doing, the teacher decides about the relevant next steps, which may be to intervene or simply to move on. Assessment does not need to lead to action in order to be formative – an appropriate decision may be to take no action to change the ongoing activity.

Feedback to Students and into Teaching

The main use of evidence in formative assessment is to provide feedback, which is a two-way process: feedback from teacher to students and feedback from students into teaching. Feedback to students is the mechanism by which future learning opportunities are affected by previous learning and as such has the potential to be a powerful influence on learning. Feedback is most obviously given by teachers to students orally or in writing but also, perhaps unconsciously, by gesture, intonation, and indeed action, such as when assigning tasks to students. The focus and form of the feedback have to be carefully judged by the teacher. The focus of the feedback influences what students pay attention to, and the form it takes determines whether it can be used to advance learning. The work of Butler (1988) has been of considerable influence in distinguishing between judgmental and nonjudgmental feedback. Feedback that helps learning should be nonjudgmental, that is, it should:

- Focus on the task, not the person
- Encourage students to think about the work, not about how "good" they are
- Indicate what to do next and give ideas about how to do it

In contrast, feedback that is judgmental is expressed in terms of how well the student has done (this includes praise as well as criticism) rather than how well the work has been done, making a judgment that encourages students to label themselves and compare themselves with others.

In formative assessment, feedback into teaching, using information that teachers pick up from observing their students, is used to inform teachers' decisions about how to help students take their next steps in learning. This feedback enables teachers to adjust the challenges they provide for students to be neither too demanding, making success out of reach, nor too simple to be engaging. In this way, teaching is regulated so that the pace of moving toward the learning goals is adjusted to ensure the students' active participation.

Student Self-Assessment

An important source of feedback to the teacher comes from students' self-assessment and peer assessment, since the criteria students use in judging the success of their work reflect their understanding of what they are trying to do. Involving students in self-assessment and in making decisions about what their next steps should be and how to take them is a shared aim of formative assessment and of inquiry-based teaching. A prerequisite for being able to judge their work is that students understand what they are trying to do, not in terms of what is to be found, but in terms of the question to be addressed or problem to be solved. In addition, they need to have some notion of the standard they should be aiming for, that is, what is "good work" in a particular context. The criteria to be used by students in assessing their work can be conveyed implicitly through feedback from the teachers or developed more explicitly through brainstorming with students about, for instance: What makes a good plan for an investigation? What should be included in a good report of an inquiry? Understanding the goals of their work and the quality criteria to be applied supports the aim of increasing students' responsibility for their work and develops their recognition of what is involved in learning (metacognition).

In Summary

Key practices of using assessment formatively to develop students' ability to inquire are:

- Students being engaged in expressing and communicating their understandings and skills through classroom dialogue, initiated by questions framed to elicit students' thinking
- Feedback to students that provides advice on how to improve or move forward and avoids making comparisons with other students

- Teachers using information about ongoing learning to adjust teaching so that all students have opportunity to learn
- Students understanding the goals of their work and having a grasp of what is good quality work
- Students being involved in self-assessment so that they take part in identifying what they need to do to improve or move forward
- Dialogue between teacher and students that encourages reflection on their learning

Summative Assessment of Ability to Inquire

Summative assessment is not a continuous part of teaching and learning as is the case for formative assessment where skills and understanding are assessed during inquiry-based activities. Rather, it takes place at certain times when a summary of students' achievement is needed in order, for example, to report to parents, students' next teachers, and the students themselves; to select students for courses; to accredit their learning; or to monitor progress of individuals and groups of students as they pass through the school. Information for these purposes may be gathered in various ways, the most common falling into three main groups:

- Tests or special tasks given under controlled conditions or embedded in classroom activities
- Summarizing information gathered by teachers during their work with the students over a period of time
- Building a record over time, as in a portfolio created by teachers and/or their students

The choice of method will depend on the use to be made of the result and the demand that the particular use makes for reliability of the results. The reliability of an assessment refers to the extent to which the results can be said to be of acceptable consistency or accuracy for a particular use. Reliability is defined as, and, where possible, estimated quantitatively, by the extent to which the assessment, if repeated, would give the same result. In the case of formative assessment, judgments are made about action to take in a particular situation involving only the teacher and students, and the notion of making a repeatable judgment is not relevant. No judgment of grade or level is involved, so reliability in this formal sense is not an issue in formative assessment. However, when assessment results are used by others and may involve students being compared or selected, as in summative assessment, reliability becomes important.

It is important to realize that the extent to which the reliability of an assessment can be raised is limited by the interaction of reliability and validity and the effect that optimizing one has on the other. This is best illustrated in relation to items in a test. Attempts to ensure high reliability will inevitably favor the inclusion of items that can be consistently marked or marked by machine, limiting the range of outcomes that can be covered in the test and lowering its validity. Extending the range of what is assessed to the application of knowledge and skills requires the use of more open-response items where judgment is needed in marking, inevitably reducing the reliability. Thus there is a trade-off between reliability and validity which applies to all summative assessment whatever form it takes. It presents a particular problem in the assessment of skills such as involved in the ability to inquire.

Using Tests or Special Tasks for Assessing Ability to Inquire

The use of tests or special tasks is a time-honored approach to summative assessment. It is attractive because the tasks can be controlled and presented to all students in the same way, thus appearing to give the same opportunities for students to show what they can do. Tests and tasks can take different forms (e.g., written or performance) and can be presented in various ways from highly formal tests to special tasks embedded in normal work.

For ability to inquire to be validly assessed, the tasks or test items should require the use of inquiry skills. But, as noted earlier, skills are used in relation to some content, and so the task will be set in a context, requiring the skills to be used in relation to particular subject matter. Various steps can be taken to reduce the influence of knowledge of the subject matter. For instance, in Fig. 1 the subject is chosen as likely to be very familiar to the 11-year-old students concerned and thus does not constitute a barrier to engagement. In Fig. 2, all information needed about the subject for answering is given in an attempt to ensure that this knowledge is not a barrier.

Figure 1 is an item used in a survey of students aged 11 years. The subject matter is likely to be familiar to these students; thus the level of knowledge required is low, and the burden of the task is about conducting a fair test. The format for answering – and the requirement of the scoring rubric for the answer in each box to be correct – makes the chance of succeeding by guessing very low. But it also means that students have to read and understand the instructions for recording their answer; otherwise, there is a risk of failure for reasons other than not having the skill needed to the answer the question.

Figure 2 is an item written for the PISA surveys of 15-year-olds (OECD 2000). Students are asked to use the given information to support alternative conclusions about action that could be taken. The information is authentic and presents the sort of problem that students able to inquire should be able to engage with. The two parts to the task illustrate the uncertainty of interpreting scientific information in certain cases. In theory, all the information is provided, and the students are told how to interpret the chart. They do not need to know how carbon dioxide, methane, and particles and their effects on clouds cause heating and cooling. However, it is arguable that without any knowledge of these things, the question is likely to be meaningless, and they are unlikely to engage with the problem posed.

Figures 1 and 2 illustrate some of the features of written test items that endanger the validity of the test. The most obvious is the inevitable demand for reading and understanding the question and, depending on the answer format, for writing ability. In addition, the attempt to place the task in a context that can seem real to the student means that some sort of “story line” is presented as a context for the task. Students have to read and engage with the context in order to respond to the question. There is evidence that these features of the item do affect students’ measured attainment. The effect of the choice of a particular context can be reduced by using a range of contexts, balancing out the effect of any one. But since there is a limit to the length of a test, this would mean a larger number of shorter items, each assessing a small part of the ability to inquire. It raises the question of whether this is a valid way of assessing the ability to combine different skills in conducting a whole inquiry.

Some of the deficiencies of written tests – particularly the dependence on reading and writing – can be avoided by performance items, where students carry out a whole or part of an investigation with real objects and equipment. The question still has to be presented to the student who has to engage with it as if it were his or her own, and the situation is far from that of a normal classroom, since the students may be working alone (sometimes in pairs) with an administrator present to observe their actions. However, it does give an opportunity for student to explore, try out approaches, and start again if necessary. The main problem is one of generalizing from the very small number of extended investigations that it is feasible for any one student to undertake. Again it is the context that has a strong influence on the outcome. There is strong research evidence that students who perform well in one investigation will not necessarily do so in another testing the same skills but in a different context. Consequently, it is useful to consider alternatives to tests.

Summarizing Teacher-Based Assessment

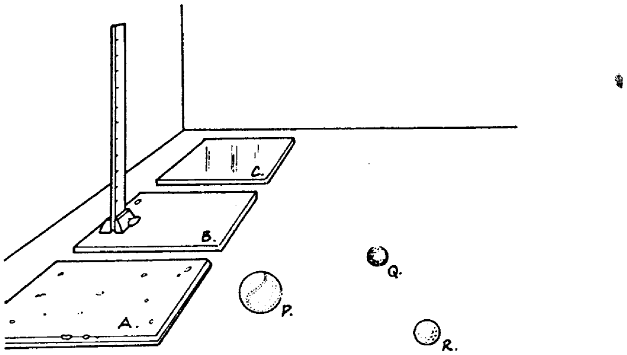
One of the main alternatives to tests draws on the fact that the experiences that students need in order to develop desired skills also provide opportunities for their progress to be assessed. The key factor is judgment by the teacher. Assessment by teachers can use evidence from regular activities supplemented, if necessary, by evidence from specially devised tasks introduced

Inquiry, Assessment of the Ability to, Fig. 1 From APU Report of Science at age 11, DES 1985

Emma and Anita were finding out if the surface on which a ball is bounced makes a difference to how high it bounces.

They found three different kinds of surface, which they called A, B and C.

They also had three different balls P, Q and R.



For a fair test what should they change in their trials and what should they keep the same?

Tick Change or Not change for each thing below:

	Change	Not change
The ball	☐	☐
The surface	☐	☐
The height it is dropped from	☐	☐

to provide opportunities for students to use the skills to be assessed. The limitation on the range of evidence that can be obtained through a test does not apply when assessment is teacher based.

There are other advantages that go beyond more valid assessment of understanding and inquiry skills, since a greater range of competences can be included. Observation during regular work enables information to be gathered about processes of inquiry rather than only about products.

Assessment by teachers is not just a matter of teachers using their individual judgments about what evidence to use and how to interpret it. Summative assessment by teachers must follow agreed procedures and be subject to quality control measures appropriate to the use of the results, that is, stricter control for higher-stakes use. Evidence of students' use of inquiry skills will be gathered by various means, as for formative assessment, and interpreted using broad criteria relating to skills development. Procedures for making judgments generally involve some to-ing and fro-ing between data and criteria to make an "on-balance" judgment as to which particular criteria are met. It is common for criteria to be identified at different "levels," so that the outcome of the assessment can be expressed in terms of the level at which a student is performing. Levels are produced by mapping the progress of students in a particular area of learning, using evidence from research

Read the following information and answer the questions which follow.

WHAT HUMAN ACTIVITIES CONTRIBUTE TO CLIMATE CHANGE?

The burning of coal, oil and natural gas, as well as deforestation and various agricultural and industrial practices, are altering the composition of the atmosphere and contributing to climate change. These human activities have led to increased concentrations of particles and greenhouse gases in the atmosphere. The relative importance of the main contributors to temperature change is shown in Figure 1.

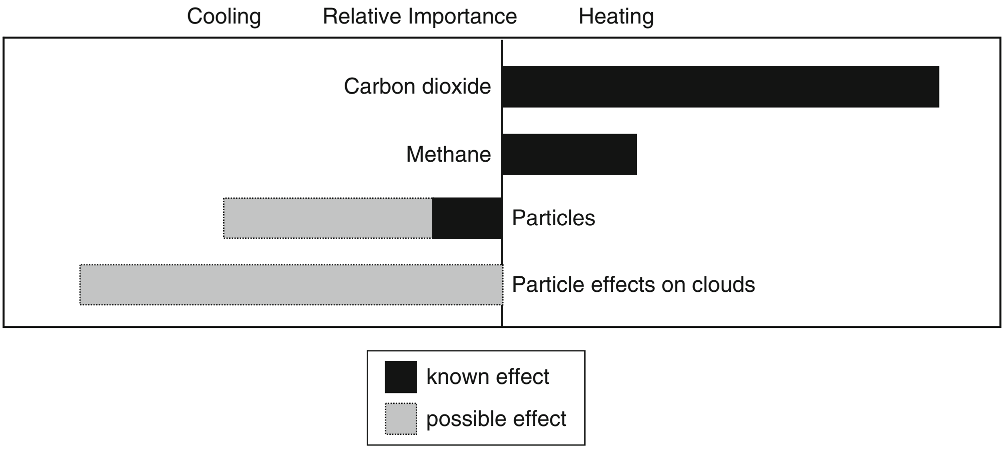


Figure 1: Relative importance of the main contributors to change in temperature of the atmosphere.
Source: adapted from http://www.gcrio.org/ipcc/qa/04.html

Bars extending to the right of the centre line indicate a heating effect. Bars extending to the left of the centre line indicate a cooling effect. The relative effect of 'Particles' and 'Particle effects on clouds' are quite uncertain: in each case the possible effect is somewhere in the range shown by the light grey bar.

Figure 1 shows that increased concentrations of carbon dioxide and methane have a heating effect. Increased concentrations of particles have a cooling effect in two ways, labelled 'Particles' and 'Particle effects on clouds'.

Item 1:

Use the information in Figure 1 to support the view that priority should be given to reducing the emission of carbon dioxide from the human activities mentioned.

Item 2:

Use the information in Figure 1 to support the view that the effects of human activity do not constitute a real problem.

Inquiry, Assessment of the Ability to, Fig. 2 PISA assessment of Science 2000 and from teachers' experience. Some care has to be taken in using levels, however, as there is a risk of students becoming labeled and indeed labeling themselves in terms of levels achieved (Harlen 2013).

The most commonly expressed criticism of assessment by teachers concerns the reliability of the results. It can indeed be the case that, when no steps are taken to assure quality, teachers' judgments are prone to a number of potential errors. However, there are various ways in which the reliability of teacher-based judgments can be brought to a level comparable with that of tests. These include group moderation and the use of exemplars. In group moderation, teachers meet to review samples of students' work. The purpose is not to verify decisions about particular students' work, rather to arrive at shared understandings of criteria and how they are applied, thus improving the reliability of future assessments. The provision of examples of students' work (which can be in the form of video recording of inquiry in action) shows how certain aspects relate to the criteria of assessment, clarifying the meaning of the criteria in operation. Good examples also indicate the opportunities that students need in order to show their achievement of skills.

Building a Record over Time

This approach to summative assessment creates a portfolio that is not a sample of all a student's work over a period of time, but reflects the best performance at the time of reporting. The evidence is accumulated gradually by retaining what is best at any time in a folder, or other form of portfolio (including computer files), and replacing pieces with better evidence as it is produced. The evidence can take a variety of forms from photographs, videos, artifacts, as well as writing and drawings. The approach enables students to have a role in their summative assessment by taking part in the selection of items in the folder or portfolio, a process for which they need some understanding of the broad goals and quality criteria by which their work will be judged. It is important that time is set aside at regular intervals specifically for students to review their work. This gives them time not only to decide what to put in the "best work portfolio" but also to consider what they can improve.

The final form of the portfolio is assessed at the time when a summative judgment is needed, either by the teacher or by external assessors, depending on the purpose and requirements of the assessment procedures. The process involves comparing evidence from the portfolio with the criteria to identify the "best fit."

In Summary

Some key features of summative assessment of ability to inquire are:

- Taking place at certain intervals when achievement has to be reported
- Requiring methods which are as reliable as possible without endangering validity
- Involving students using inquiry skills within a context, the nature of which is likely to affect students' engagement and performance
- Reporting achievement in terms of criteria describing the extent of use of inquiry skills
- Involving some quality assurance procedures commensurate with the use made of the results
- Where appropriate, involving students in the assessment and in this way contributing to their learning

Cross-References

▶ Assessment of Doing Science
▶ Assessment: An Overview
▶ Formative Assessment
▶ Summative Assessment
▶ Test
▶ Validity and Reliability of Science Assessments

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Inquiry as a Teaching Strategy

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Keywords

Enquiry; Explanations; Inquiry; Investigations; Practices of science; Teaching strategy

Content, Context, and Practices

Inquiry as a teaching strategy operationalizes the teaching of scientific inquiry as content by providing a context for the teaching and learning of the practices of science. The need for contextualizing the content of science within the practices of science has a long history. In 1910, John Dewey argued that a conceptual, discipline-based form of scientific knowledge could not be learned in isolation from the "intelligent practice" of science. The publication of Joseph Schwab's *The teaching of science as enquiry* (1962) proposed that science teachers should provide opportunities for their students to engage in the practices of science as a strategy for the teaching and learning of science. The practices of science have recently been defined by the National Research Council [NRC] (2012) in the United States as:

1. Asking questions
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Engagement with the practices of science, it was argued, should be built around an increasing student sophistication in developing scientific questions: the gathering of evidence, the manipulation and analysis of that evidence, and the proposal and communication of scientifically justifiable explanations. Major impediments to the broad adoption of Schwab's ideas have been the resilience of an abstract curriculum that privileges concepts over context and the associated issue of teachers' cultural reproduction of a traditional view of science education.

Arising from these impediments is a preconception that equates the teaching of inquiry with a single teaching strategy: open-ended activities that are "hands-on" for students and "hands-off" for teachers. This preconception, in turn, justifies many teachers not teaching inquiry. The reasons that are given to support this decision (which is often made subconsciously) include the perceived difficulty of teaching from a constructivist perspective, the added time and energy required, and teachers' perceived need to meet the expectations of the curriculum. Other concerns include the physical limitations of the classroom, a belief that safety will be compromised, and the capacity of students to engage with the levels of analysis, argumentation, and evaluation described in documents such as the *National Science Education Standards* (NRC 1996). Support from colleagues, the costs of apparatus and consumables, placing material in the proper sequence, and the demand of preparing students for further study are also cited as concerns.

For teachers, to move beyond these reasons and embrace inquiry as a teaching strategy requires the development of an identity that allows for the questioning of contemporary science education. An important component of this transformation is to recognize that inquiry, as a teaching strategy, should simultaneously reflect the practices of science and the development of scientific knowledge about the natural world. The Science Teaching Standards of the *National Science Education Standards* (NRC 1996, pp. 27–54) provide a number of criteria through which teachers can begin to question and assess their abilities for, and understandings of, the teaching and learning of inquiry:

1. Teachers of science plan an inquiry-based science program for their students.
2. Teachers of science guide and facilitate learning.
3. Teachers of science engage in an ongoing assessment of their teaching and of student learning.
4. Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science.
5. Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning.
6. Teachers of science actively participate in the ongoing planning and development of the school science program.

These standards provide teachers with a foundation from which to develop opportunities for using inquiry as a teaching strategy. To build on that foundation, teachers need to understand two other important aspects of the shift in their teaching practice. First, the practices of science can be considered as both learning outcomes and teaching strategies, as they provide both the means and ends of science teaching and learning. As learning outcomes, students should develop the abilities of inquiry through their work with the practices of science, concomitantly coming to an understanding of how scientific knowledge evolves. As teaching strategies, the practices of science open opportunities for learning both core disciplinary concepts (see NRC 2012, pp. 103–200) and the concepts that transcend the disciplinary boundaries, such as cause and effect, structure and function, and stability and change (see NRC 2012, pp. 83–102). Second, there is no evidence that any one teaching approach is more effective than any other in actively involving students in developing the knowledge, understandings, and scientific abilities that constitute inquiry. The selection of the appropriate strategy at the appropriate time is very much the realm of the professional science teacher, hence the importance attached to the collaborative and collegial learning of teachers as they seek to shift their practice. In selecting the appropriate strategy, teachers must be explicit in the learning outcomes that they are seeking, the scaffolding that will be needed if students are to achieve those outcomes, and the links between content and practices. Developing those links through inquiry opens opportunities for students to become proficient in science (Duschl et al. 2007), giving them the capacity to:

1. Know, use, and interpret scientific explanations of the natural world
2. Generate and evaluate scientific evidence and explanations
3. Understand the nature and development of scientific knowledge
4. Participate productively in scientific practices and discourse

Central to the use of inquiry as a teaching strategy is the active engagement of students in investigations in which students answer scientific questions through the practices of science. The use of the word “practices” is a reflection of the evolution of thinking around inquiry as a teaching strategy. Following the US publication of *Inquiry and the National Science Education Standards* (NRC 2000), the essential features of investigations were seen to be the extent to which a:

1. Learner engages in scientifically oriented questions.
2. Learner gives priority to evidence in responding to questions.
3. Learner formulates explanations from evidence.

4. Learner connects explanations to scientific knowledge.
5. Learner communicates and justifies explanations.

With the publication in the United States of *A Framework for K-12 Science Education* (NRC 2012), the emphasis was been broadened and deepened to incorporate the practices of science. If students are to develop proficiency in science, such a progression through investigations must link and reiterate the practices of science to both the appropriate core disciplinary concepts and the concepts that transcend the disciplinary boundaries. Investigations are a foundation on which students can "learn about experiments, data and evidence, social discourse, models and tools, and mathematics and for developing the ability to evaluate knowledge claims, conduct empirical investigations, and develop explanations" (Bybee 2011, p. 38). This emphasis recognizes that the abilities and understandings that students develop, and display, will demonstrate a progression over time. Students require substantial scaffolding in the practices of science if they are to become proficient, and a well-designed progression will guide students through a number of graduated steps. Important aspects of this guiding include giving meaning to the investigation in terms of other student learning and allocating adequate time for the investigation.

Within the literature, the graduated steps of inquiry are generally viewed as a continuum, with the level of complexity being influenced by factors such as the amount of information given to the student, the level of teacher guidance that is offered, and the sophistication of the students' abilities. The least complex level of inquiry is generally known as a confirmation (or verification) inquiry. Students are generally provided with the question and procedure, and the results are generally expected. This level has value in verifying concepts and training in the safe and correct use of apparatus. The next level of complexity, the structured inquiry, investigates a research question using a prescribed procedure. Confirmation and structured inquiries make up the majority of textbook investigations, but for students to become proficient in science, they must have opportunities to carry out investigations of greater complexity. Moving further along the inquiry continuum, the guided inquiry gives students the opportunity to develop their own investigation in response to a question. The most complex investigation, or open inquiry, requires students to develop their own topic-related research question and strategies for gathering, analyzing, and reporting their data. It is unreasonable and counterproductive to expect students to conduct complex investigations without having experienced some success in less complex investigations. Similarly, to limit students to less complex investigations is to stifle student interest and success. A well-designed progression to increasingly complex investigations is crucial for student learning and success.

Cross-References

▶ Curriculum Emphasis
▶ Inquiry, as a Curriculum Strand
▶ Inquiry, Assessment of the Ability to
▶ Inquiry, Learning Through
▶ Learning Progressions
▶ Scaffolding Learning

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Inquiry, As a Curriculum Strand

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Keywords

Inquiry; Inquiry as content; Learning about inquiry; Science curriculum

There and Back Again: From Inquiry into Social Problems to Disciplinary Scientific Inquiry

Curriculum has many meanings. Here, it is broadly conceptualized as comprising the domains of, and rationales for, subject matter and intended learning outcomes, nature and organization of instruction and learner experiences, and interactions among students and teachers within the immediate settings of classroom and school, as well as broader societal contexts. The meanings of *inquiry*, particularly in the context of science education, also are numerous. These include scientific inquiry (how scientists conduct their practice), inquiry teaching (as means, pedagogy, or an instructional approach to facilitate science content learning), inquiry learning (as an active process of learning, which assumes that students construct understandings in ways similar to how scientists develop claims to scientific knowledge), and inquiry as content (as ends, or subject matter to be learned) (Abd-El-Khalick et al. 2004; Anderson 2007). Inquiry as content includes several outcomes related to developing the skills, procedural knowledge, and habits of mind requisite for *doing* scientific inquiry, as well as learning *about* scientific inquiry, that is, its underlying epistemological underpinnings. In the context of these broad definitions, this entry discusses inquiry as an organizing theme or strand in science curriculum and focuses on the historical treatment of inquiry as content within such curriculum. For discussions of inquiry teaching and inquiry learning, the reader is referred to the entries *Inquiry, as a teaching strategy* and *Inquiry, learning through*, respectively. This entry, it should be noted, mostly is focused on the context of science education in the USA. This country is used as a case study to illuminate some broad historical patterns and trends, patterns which tend to have similarity (if not always shared time frames) with the treatment of inquiry as a curriculum strand in other national contexts.

Deboer (2004) traced the introduction of science into US school curriculum to the middle of the nineteenth century alongside other mainstay subjects of school curriculum, such as mathematics and grammar. Prominent scientists of the time, such as Thomas Huxely, argued that observation and inductive reasoning were the distinctive features of scientific investigation that should characterize science learning, propel student intellectual development, and discipline student minds (as stipulated by the theory mental discipline, which was the contemporary, dominant theory of learning). This view, Deboer continued, compelled other prominent contemporary intellectuals to champion the structuring of science and laboratory instruction as a process of scientific investigation whereby students experience natural phenomena firsthand, "make their own investigations and draw their own inferences" (Herbert Spencer 1864 as cited in Deboer 2004, p. 23). In 1892, the Committee of Ten of the US National Education Association strongly endorsed the use of laboratories in secondary science education. The Committee emphasized the need to abandon the simple memorization of facts in favor of the personal development of students' reasoning skills and their abilities to inductively acquire scientific understandings.

By the turn of the twentieth century, social issues associated with urbanization, immigration, and other problems brought about by the Western industrial revolution of the previous century were in full swing. Coupled with the influence of John Dewey's pragmatism, education was now more focused on practical work, which was deemed necessary to solve social and economic problems. The latter focus also aligned with child-centered approaches championed by Dewey and his calls to engage students with investigating questions related to their experiences. As early as 1910, there were calls to include in science curriculum more useful applications to the real world. With the release in 1918 of the Cardinal Principles of Secondary Education by the US Department of the Interior, the applied nature of laboratory work in science education was bolstered with an emphasis on scientific reasoning and problem solving abilities needed to address socially significant issues. In 1932, the Thirty-First Yearbook of the US National Society for the Study of Education identified training in *the* scientific method and the application of this method to solving social issues and students' own problems to be among the major themes that should be present in the science curriculum.

By the 1950s, criticisms of the science curriculum's emphases on addressing student personal interest, practical applications, and societal problems were mounting. Concerns were directed at the lack of academic and disciplinary rigor, and training in scientific methods and processes. The Soviet Union launching of the Sputnik satellite in 1957 exacerbated these concerns – which now were directly linked with US national security, interests, and economic competitiveness – and precipitated unprecedented US federal funding for developing new science curricula, the now dubbed Alphabet Curricula or First Generation Projects. These curricula were academically rigorous, focused on disciplinary content knowledge and scientific processes, and aimed toward developing the next generation of practicing scientists. The term "inquiry" was now formalized as describing a major theme in the science curricula of the 1960s and 1970s. These curricula were particularly influenced by Joseph Schwab's writings, which stressed the need to address both the substantive and syntactical structures of science, the latter specifically referring to the application of cannons of evidence toward developing claims to scientific knowledge. Schwab believed that "scientific content and processes were intimately connected and inseparable . . . [and that] content should be taught in relation to the methods that generated that knowledge" (Deboer 2004, p. 28). Schwab did not argue that students should be able to conduct scientific inquiries themselves, but rather understand the nature of such inquiry. Thus, learning *about* scientific inquiry became part and parcel of science curricula. Science educators now were explicitly distinguishing between two meanings of inquiry in the context of science education, namely, learning about "inquiry as content," that is, "as it appears in the scientific enterprise," and "inquiry as pedagogic technique," that is, "using the method of scientific inquiry to learn some science" (Rutherford 1964, p. 80).

Somewhat parallel projects in England began about 5 years after the first of the US projects, and impacted in major ways on that country and the large number of former British colonies around the globe. These were collectively known as the "Nuffield Projects," now often termed the second-generation projects. They were much more strongly shaped by expert school science teachers. To a considerable extent, these projects focused much more on "inquiry as pedagogic technique" and, for some projects such as the Schools Council Integrated Science Project (SCISP), embedded this inquiry in "real" contexts and linked it closely with problem solving. These uses of and contexts for inquiry were early (1970s) forms of Science-Technology-Society curricula.

Difficulties for US students and science teachers associated with the academic rigor of the early Alphabet curricula, coupled with the debates of the 1980s regarding the effectiveness of the 1960s and 1970s inquiry-oriented curricula, shepherded in the USA a return to a focus on "inquiry" that enables students to address broader societal issues in an increasingly scientific and technologically laden world. These efforts first took the form of the Science-Technology-Society curricula of the 1980s and 1990s, a perspective also emphasized in the major Canadian report of the early 1980s *Science for Every Student*: *Educating Canadians for Tomorrow's World*. This turn or return came into full swing during the last decade of the twentieth century, which witnessed the release of several US reform documents that also had some impact internationally, most notably the 1989/1990 *Science for All Americans* and 1993 *Benchmarks for Science Literacy* (Benchmarks) by the US American Association for the Advancement of Science, and the 1996 *National Science Education Standards* (Standards) by the US National Research Council (NRC). Similar documents included the 1997 Canada's Council of Ministers of Education *Pan-Canadian Science Project* and the 1998 report, *Beyond 2000*: *Science Education for the Future*, in the UK.

These documents solidified the construct of scientific literacy as the major focus of school science education in the USA and in some other parts of the world. This focus chiefly aimed at preparing citizens able to make informed decisions regarding science-related personal and social issues and engage meaningfully in democratic societies that were becoming increasingly dependent on the enterprise of science. Interestingly, the *Benchmarks* included understandings about scientific inquiry as a subset of the more overarching construct of nature of science. These included an understanding of the role of evidence, logic, and imagination in scientific inquiry (lack of a universal scientific method), as well as the aims of generating verifiable predictions and explanations in which scientists' biases and idiosyncrasies are diminished. In comparison, the *Standards* included separate learning outcomes for students' understandings of nature of science, students' understandings about scientific inquiry, and their ability to do scientific inquiry. The latter included abilities related to questioning; designing and conducting investigations; formulating explanations, models, and predictions; and communicating and defending explanations. The *Standards* emphasized understandings about inquiry including that investigations and methods are guided by questions and that scientific explanations are developed from evidence and current scientific knowledge.

Scientific inquiry, in the sense of capturing what scientists do, has been a fixture in school science curricula over the past century and a half, that is, for what is essentially the history of school science education. Nonetheless, as Deboer (2004) concluded, there emerges – at least in the US context – a pattern related to the function and intended outcomes of inquiry as content in such curriculum. In the latter half of the nineteenth century, scientific inquiry was intended to develop in students what was deemed the pinnacle of scientific method of the time, that is, inductive reasoning. The first half of the twentieth century emphasized inquiry as means to address applied issues and to enable students to solve social problems beyond the realm of disciplinary science. This emphasis gave way in the curricula of the 1960s and 1970s to a renewed focus on scientific disciplines and inquiry as scientific method, with the aim of preparing future scientists. Next, the theme of scientific literacy in the reform efforts of the 1980s and 1990s revived the focus on inquiry as a crucial component for addressing, and making decisions about, science-related personal and social issues. These reforms delineated goals for learning to do scientific inquiry – now represented as a varied set of integrated abilities and skills as compared to a universal scientific method – and learning about scientific inquiry.

The next wave of reforms in the USA, which was initiated with the NRC's 2012, *A Framework for K-12 Science Education*: *Practices*, *Crosscutting Concepts*, *and Core Ideas* (Framework), fits nicely within the above pattern. The construct of scientific literacy and goal of enabling students to address broad social problems hardly receive any mention in the *Framework*. While the *Framework* highlights the role of science in informing citizens' decision making, the two major goals for K-12 science education are identified as "(1) educating all students in science and engineering and (2) providing the foundational knowledge for those who will become the scientists, engineers, technologists, and technicians of the future" (NRC 2012, p. 12). School science education would deepen students' "understanding of the core ideas of . . . [scientific] fields," and enable them "to engage in public discussions on science-related issues, to be critical consumers of scientific information related to their everyday lives, and to continue to learn about science throughout their lives" (NRC 2012, pp. 8–9). There clearly is a return to a disciplinary focus in science curriculum (albeit coupled, for the first time, with engineering) along with strong Schwabian undertones of intertwining the learning of core disciplinary ideas with scientific processes. Scientific inquiry persists under the label of scientific (and engineering) practices, which include engaging students with and learning about: asking questions, developing and using models, planning and conducting investigations, analyzing and interpreting data, using mathematical and computational reasoning, constructing explanations and arguments, and handling information (NRC 2012, p. 1).

Pendulum swings between emphasizing inquiry-related curricular outcomes that prepare students to *either* engage in disciplinary scientific inquiry *or* address broader social problems seem to derive from a one-dimensional approach. Such an approach to inquiry as a curriculum strand or inquiry as content will, in all likelihood, fail to capture or serve the complex and nuanced agenda of precollege science education required to address the needs of students, future citizens, and future scientists in the twenty-first century. Abd-El-Khalick (in Abd-El-Khalick et al. 2004) argued for a multidimensional heuristic that defines a space of inquiry-related outcomes, whereby subsets of these outcomes are brought to the forefront – and others pushed to the background – of curriculum, teaching, and learning along the horizontal and vertical dimensions of school science education. One dimension would include a set of target knowledge domains and understandings, including conceptual/disciplinary, epistemic, and social, to be learned with inquiry. A second dimension would include a range of inquiry-related abilities and skills, such as problem-posing; designing investigations; gathering and interpreting data; generating, testing, and refining models and explanations; and building arguments, negotiating assertions, and communicating ideas. A third dimension could comprise a range of foundational mathematical, linguistic, manipulative, and cognitive and metacognitive skills needed to meaningfully engage in inquiry at one level or another. A fourth dimension would comprise the spheres, including disciplinary, personal, social, and cultural with which any of the aforementioned outcomes could interface, as either a context for learning about or a domain for applying inquiry. When educators – ranging from curriculum theorists to science teachers – navigate this four-dimensional space, they would consider the elements on each dimension either as possible outcomes of, or as prerequisites for meaningful engagement in, inquiry-based science education. "The former would help conceive and place more emphasis on inquiry as means (inquiry as teaching approach), while the latter thinking would help gauge the level at which students could engage in inquiry and help emphasize inquiry as ends (inquiry as an instructional outcome)" (Abd-El-Khalick et al. 2004, p. 415).

Cross-References

- ▶ Agency and Knowledge
- ▶ Context-Led Science Projects
- ▶ Curriculum Emphasis
- ▶ Curriculum Movements in Science Education
- ▶ Inquiry as a Teaching Strategy
- ▶ Inquiry, Assessment of the Ability to
- ▶ Inquiry, Learning Through
- ▶ Primary/Elementary School Science Curriculum Projects

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Inquiry, Learning Through

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Keywords

Active engagement; Computer simulations; Inquiry; Project-based science; Scaffolding; Student centered

Inquiry-based learning is part of a family of instructional techniques that situate learning in meaningful problems or questions. Inquiry learning approaches focus on having students learn disciplinary knowledge, reasoning, and epistemic practices as they engage in collaborative investigations (Hmelo-Silver et al. 2007). Inquiry is organized around the questions that scientists might ask or disciplinary problems that require scientific inquiry to resolve. Inquiry approaches to learning are student centered, meaning that active engagement on the part of the student is required. The teacher's role is to facilitate learning and engagement in science practice rather than to provide direct instruction. Of central importance to inquiry-based learning are the questions being asked. Pursuing questions situates learners in the epistemic practices that are part and parcel of the science discipline (Krajcik and Blumenfeld 2006). The nature of student investigations varies with the particular scientific discipline so that investigations might involve designing and running experiments but could also involve observational or model-based inquiry.

The theoretical basis of inquiry learning builds upon important principles from the learning sciences (Krajcik and Blumenfeld 2006). This research has demonstrated that students only learn deeply when they are active agents who engage in meaning making as they interact with the world. Substantial evidence also suggests that it is critical to situate learning in real-world contexts in which learners design their research and participate in scientific practices such as observation, representation, and explanation, as well as the social practices of science. Tools play an important role in inquiry in that they can be used to support and scaffold learners as they engage in complex inquiry practices. These tools may be relatively simple, such as a magnifying glass or a ruler, or they be more complex, such as computer simulations and data visualization instruments (Eberbach and Crowley 2009; Hmelo-Silver et al. 2007; Krajcik and Blumenfeld 2006).

Long before students formally learn about scientific inquiry, they have already developed many ways of understanding and reasoning about the natural world (Duschl et al. 2007). Such naive knowledge – developed through direct everyday experiences with phenomena and through cultural transmission – offers both opportunities and challenges for learning to participate in scientific inquiry. These knowledge sources can provide a rich foundation for asking questions, for generating evidence, and even for evaluating claims about evidence. At the same time, a major challenge for students of all ages is to learn to understand and to evaluate sources of knowledge in ways that enable them to distinguish personal beliefs from empirical evidence, to connect evidence to explanations (Duschl et al. 2007), or to connect their observations of everyday phenomena to the development of new knowledge (Eberbach and Crowley 2009).

These challenges affect the development of scientific reasoning and are evident throughout inquiry. To illustrate the challenges of learning through inquiry, we briefly consider observational practice, which can be a powerful means of making sense of the world and which plays a central role in how scientists develop new knowledge (Eberbach and Crowley 2009).

Although observation is often treated as a simple skill of noticing surface features, actual systematic observation is a complex practice that coordinates disciplinary knowledge, theory, and certain habits of attention. Observational practice includes asking questions of phenomena. These questions focus attention and filter complexity; questions connect to disciplinary problems and goals throughout the inquiry process. The questions that scientists ask guide their observations and ultimately the data they record and collect. These data are often transformed into inscriptions – diagrams, graphs, and line drawings – that allow new questions to be asked of data. Transforming direct observations into multiple iterations of scientific inscriptions can be useful in shaping shared questions, making evidence explicit, and critiquing each others' theories (Lehrer and Schauble, cited in Eberbach and Crowley 2009).

There are many successful examples of inquiry-based learning that are being used in a range of primary and secondary school contexts (Duschl et al. 2007; Hmelo-Silver et al. 2007). One prominent example comes from the work on project-based science at University of Michigan. PBS, used in several large urban school districts in the United States, begins each inquiry unit with a driving question, such as "Can good friends make me sick?" These questions provide a shared context that anchors inquiry and learning of disciplinary ideas. Because engagement in inquiry practices is challenging, scaffolding is critical to supporting learners. These scaffolds are often distributed across social and material resources. Social resources include teacher guidance and peer collaboration. Material resources can include technology tools that provide guidance and contexts. These scaffolds may embed expert guidance, model disciplinary thinking, and structure complex tasks so as to reduce the cognitive load (Hmelo-Silver et al. 2007). In PBS, student investigations result in the creation of artifacts, including physical models, computer simulations, or multimedia artifacts (Krajcik and Blumenfeld 2006).

There is substantial evidence that inquiry-based learning is effective (Hmelo-Silver et al. 2007). These outcomes have included effects in a large urban district on state standardized assessments (Krajcik and Blumenfeld 2006). Moreover, this effect was cumulative (i.e., more inquiry units led to greater gains) and sustained. In a study of a large and diverse school district, Lynch et al. (2005, cited in Hmelo-Silver et al. 2007) demonstrated that inquiry-based learning environments fostered better engagement and a mastery goal orientation when contrasted with a comparison group that participated in traditional instruction. This effect was equally strong for historically disadvantaged groups as it was for non-disadvantaged groups. In a meta-analysis of teaching strategies on science achievement, Schroeder et al. (2007) found that inquiry strategies were associated with a moderate to large effect on student achievement.

To deal with the challenges of inquiry-based learning and to make complex phenomena accessible to learners, many such learning environments use computer tools to scaffold learning, support inquiry, and make complex phenomena accessible to learners (Hmelo-Silver et al. 2007). Computer-based tools can be used to provide scaffolding and set contexts for inquiry. For example, in Animal Landlord, students create a chronological sequence of behavioral components in a video clip (Smith and Reiser 1998, cited in Hmelo-Silver et al. 2007). The tool highlights the disciplinary strategies for animal behavior. In BGuile, students investigate evolution of the Galapagos finches as the software provides a database and templates to help guide learners in constructing domain-specific explanations (Sandoval and Reiser 2004, cited in Hmelo-Silver et al. 2007). In WISE, scaffolds are used to provide expert guidance (Davis and Linn 2000, cited in Hmelo-Silver et al. 2007). Other scaffolds can be used to structure inquiry tasks and decrease cognitive load. In Model-It (Krajcik and Blumenfeld 2006), a computer environment allows learners to build models of natural phenomena. The software allows learners to plan, build, or test models. Learners must engage in planning before they can build their model. Moreover, the software allows students to qualitatively model relationships that express underlying complex mathematical relations, reducing the learners' cognitive load and placing the task in their zone of proximal development. Technology can also provide contexts for inquiry. These can take the form of computer simulations, visualization tools, or video. In the STELLAR project, videos of classrooms provided a context for preservice teachers to learn about educational psychology. At the same time, scaffolds structured their video analysis around instructional planning (Hmelo-Silver et al. 2007).

Learning through inquiry offers powerful ways in which learners construct content understanding and learn disciplinary practices. This is not without challenges. We demonstrated some of this with our example of observation. Inquiry changes the role of both learner and teacher. It focuses the teacher role on guiding the learning process and learners must take increased responsibility for their learning. This increased responsibility may better prepare scientifically literate citizens who are prepared to be lifelong learners.

Cross-References

- ▶ Collaborative Learning in Science
- ▶ Computers as Learning Partners: Knowledge Integration
- ▶ Inquiry, As a Curriculum Strand
- ▶ Inquiry as a Teaching Strategy
- ▶ Problem-Based Learning (PBL)

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In-Service Teacher Education

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Introduction

In-service teacher education fits broadly under the category of teacher professional development. Teacher professional development can be divided into two branches – (1) in-service teacher education and (2) professional learning communities. In-service teacher education is usually formal in nature with courses or programs offered and accredited by universities or other institutes of learning. Unlike preservice teacher education that aims to prepare inexperienced individuals to teach in classrooms, in-service teacher education is specifically catered to practicing teachers with practical experiences in the classrooms. One of the objectives for in-service teacher education is to ensure currency of knowledge that teachers have in their field of practice. These knowledges can include subject matter knowledge, knowledge of and about latest pedagogical methods, and knowledge about policies and reforms.

Teaching is a complex activity that changes with the demands of the society and the world at large. These changes in societal needs and education reforms suggest that teachers' knowledge needs to be constantly updated and innovations in teachers' practices need to keep pace with changes. Further, the rapid rate of change in scientific and technological advancement suggests that the shelf-life of knowledge that an individual possesses is shortened. Hence, constant updating and upgrading is a necessity. As such, in some countries, there is legislation on the renewal of teaching certificates/accreditation. The legislation requires in-service teachers to be involved in some form of formal professional development so that they are kept abreast of changes in the educational landscape. Even in the absence of formal legislation of teaching certification, in-service teachers are also encouraged to attend some form of professional development courses. For example, in Singapore, in-service teachers have an entitlement to 100 h of professional development to enable the in-service teachers to stay relevant and current in their practice.

Forms of In-Service Teacher Education

The forms of in-service teacher education can be mapped on a spectrum which range from short-term courses to mid-term courses to long-term courses (in ways not dissimilar from Huberman's (1989) stages of career development). Some forms of in-service teacher education are:

1. Short-term in-service courses offered by universities or colleges of education. The function of these courses is to introduce and revise with in-service teachers concepts and practices that have changed. For instance, in the last 10 years, knowledge in the area of techniques for isolation of molecules have increased exponentially and hence, in-service teachers need to be updated about these latest techniques and how to use them. Further, with the growth of information technology, in-service teachers also need to be informed how they can potentially exploit the affordances of technology to enhance their classroom practices. These short-term courses are usually conducted with specific domain learning outcomes and take the form of a single workshop that can last between 12 and 36 h. In-service teachers are usually awarded certificates of participation or proficiency when they attend these courses.
2. Mid-length in-service courses are those courses which last 2–4 weeks. Not unlike the short-term courses described above, these mid-length courses are also aimed at informing teachers of the latest development and changes in educational policies or domain knowledge. Unlike the short-term courses, these mid-length courses are usually structured in such a way that will allow the participating in-service teachers to trial some of the ideas from the courses in their classrooms and to be able to share the outcomes of their enactment. These courses are usually conducted concurrently with the school academic term so that trial implementation is made possible. These mid-length in-service courses are more agentic for in-service teachers as there are opportunities for them to contribute to the knowledge pool of the course. As such, there are also opportunities for in-service teachers to form themselves into professional communities of practice (see Lave and Wenger 1998) through these courses.
3. On the other end of the spectrum are longer-term in-service courses leading to formal accreditation such as a master's or doctor of philosophy graduate degree. These long-term in-service teacher education courses are usually offered by colleges of education or tertiary education institutions with graduate schools. This form of in-service education functions to fulfil the needs of in-service teachers who like to specialize in a particular area of their practices. For instance, an

in-service teacher working with children requiring special needs may find it meaningful to pursue a master's degree program specializing in understanding and helping students with special needs. This form of in-depth study will likely increase the knowledge, practice, and professionalism of the teacher. These forms of in-service teacher education will usually require the in-service teachers to go back to school formally, and learning usually takes the form of lectures, laboratory exercises, group discussions, and readings. In many graduate programs, the in-service teacher participants are usually also required to be involved in some form of critical inquiry of their practices. Depending on the demands of legislation, societal needs, and changes in domain knowledge, the frequency and forms of in-service teacher education will vary from country to country and even within the same country.

Issues with In-Service Teacher Education

There are many issues which in-service teacher education researchers and policy makers are faced. Firstly, it is often difficult to track and measure the impact of various forms of in-service teacher education (Day 1997) and how they contribute to changing/improving the practices of teachers. The causal relationship between in-service teacher education and teacher change is difficult to establish, and hence, in-service teacher education providers find it difficult to evaluate the impact of the courses. Secondly, while in-service teacher education is important and is encouraged, taking teachers out of the classrooms results in the loss of curriculum contact time with students. This disrupts the routine and the learning of the students. As such, schools and the education system as a whole need to think of ways to provide in-service teachers with learning opportunities that result in minimum disruption to school life. In general, the in-service teacher education community needs to develop more robust means to evaluate and assess impact of in-service teacher education on both short-term as well as long-term programs and relate these to the improvements in teachers' practices and their contributions to improving educational outcomes. Systematic tracking of in-service teacher education (e.g., in the form of a personal portfolio) either for personal development or for career advancement will help.

Cross-References

- ▶ Communities of Practice
- ▶ Science Teachers' Professional Knowledge
- ▶ Teacher Contextual Knowledge
- ▶ Teacher Craft Knowledge
- ▶ Teacher Professional Development

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Instructionally Sensitive Assessments (Close, Proximal, Distal Assessments)

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Keywords

Curricular validity; Instructional alignment; Instructional validity; Opportunity to learn (OTL)

Instructional sensitivity refers to the validity of the inferences made about the ability of a test or test item to reflect or differentiate the instruction received by students, based on their performance on that test or test item. The focus of instructional sensitivity is the overlap between test and instruction. The scores produced by an instructionally sensitive test should distinguish accurately between students who have and have not been taught a given content or those who have and have not been effectively taught that content. Because of the importance of the validity of test interpretations, instructional sensitivity should be regarded as a psychometric property of the tests – as important as other psychometric properties (Polikoff 2010). Interpretations of the effectiveness of teachers' and schools' instructional practices are not valid if they are based on instructionally insensitive tests.

Two terms closely related to instructional sensitivity are instructional validity and curricular validity. Instructional validity was originally introduced by Feldhusen et al. (1976) to refer to two sources of data for evaluating the validity of test score interpretations: the specification of the knowledge or performance domain being tested and evidence that instruction on the specified domain was provided. They argued that the concept of content or curricular validity only considered the content of the test, but it did not provide information about whether and how that content was delivered to students. In 1979, McClure used the term instructional validity in the Debra P. vs. Turlington case. He defined it as "an actual measure of whether the schools are providing students with instruction on the knowledge and skills measured by the test" (p. 683, emphasis added). He defined curricular validity as "a measure of how well test items represent the objectives of the curriculum" (p. 682). It is important to note that McClure regarded curricular validity as "theoretical" and instructional validity as empirical since judgments on the latter need to be supported by evidence that the students were exposed to the knowledge and skills required to answer the test correctly. This distinction helps to appreciate that, even when a test appears to have an appropriate "fit" to a curriculum based on the content areas sampled, the fit does not ensure that students have actually been instructed on these content areas. That is, an assessment that has curricular validity may have different degrees of instructional validity across classrooms. The connection between instructional validity and instructional sensitivity is direct. Both terms focus on the need of evidence of the instruction received by students on the topics being tested. Curricular validity is part of instructional sensitivity. While instructional validity can be used interchangeable with instructional sensitivity, curricular validity cannot.

Two other terms usually linked to instructional sensitivity are instructional alignment and opportunity to learn. They are techniques to measure the characteristics of instruction to which students are exposed, and, therefore, they are not conceptually equivalent to instructional sensitivity. Instructional alignment refers to the match between the content of instruction and the content of an assessment based on teacher's reports about the content being taught and the cognitive demands with which the content was taught. Opportunity to learn (OTL) refers to whether or not students have had the opportunity to study a particular content. It is a concept introduced in the First International Mathematics Survey in the 1960s with the purpose of ensuring valid comparisons in international testing programs. While there are multiple measures of OTL, basically, they address whether certain content was covered and, in some instruments, what proportion of time is spent covering it.

An important source of deviations in defining instructional sensitivity lies on the conceptualization of the instruction students received – "what" aspect of the instruction researchers paid attention to. Two aspects of instruction have been the focus of the research on instructional sensitivity: the content being taught and the quality with which the content is taught. This difference is relevant when it comes to the methods used to gather information about the instruction that students receive.

Examining Instructional Sensitivity of Tests

There are three major categories of methods for examining instructional sensitivity (Polikoff 2010): statistical, instruction-based, and judgmental. Statistical methods focus on item statistics based on students' responses to items. One especially important item statistic is the pretest-posttest difference index (PPDI) proposed in the 1960s. PPDI is the proportion of students (p value) passing the item on the posttest minus the proportion of students passing the item in the pretest. The difference in pre-instruction and post-instruction scores is considered as an indicator of instructional effectiveness. PPDI is considered to be a robust indicator because it allows detection of the effects of instruction (on different tests and with different samples of students), it is easy to implement and understand (as gain scores), and its use in item selection for tests leads to a better ability to distinguish between students who have and have not received instruction (Polikoff 2010). Other item statistics involve the use of item response theory (IRT). One of them is ZDIFF, the normalized difference between IRT-based item difficulty estimates on the pretest and the posttest or from two different samples of students (see Polikoff 2010).

Instruction-based methods focus on two sources of information, students' responses to items, and some type of measure of the instruction students received. The study of the content and/or the quality with which it is delivered has used a wide variety of approaches. These approaches include multiple measures of instruction (e.g., teachers' reports about content covered or content taught/not taught, quality of instruction measured by direct observation or teacher surveys, or analysis of curriculum materials), multiple research designs (e.g., comparing expert teachers vs. less expert teachers), and multiple analytic methods for examining the link between instruction and performance (e.g., simple comparisons of means, regression, IRT, hierarchical linear modeling – HLM). Studies using instruction-based methods have produced conflicting results about instructional sensitivity (Polikoff 2010).

Judgmental methods use experts' judgments about tests and test items. Judgments can target (1) the alignment or congruence of the test items with learning goals, targets, or objectives (henceforth learning goals) using a simple rating of yes/no/unsure; (2) the appropriateness or suitability of test items to measuring certain learning goals using a rating scale; (3) the correspondence of items to learning goals; (4) the curricular learning goals test items appear to assess; and (5) the clarity with which the curricular learning goals tapped by a test help teachers to understand what is being assessed. Unfortunately, little to none empirical support exists about the effectiveness of examining instructional sensitivity by focusing on any of these targets.

Developing Instructionally Sensitive Tests

All the methods and approaches mentioned above focus on examining the instructional sensitivity of extant tests, not the development or instructionally sensitive tests. Recently, an approach for developing instructionally sensitive tests has been proposed (Ruiz-Primo and Li 2008). The approach generated by DEISA (Developing and Evaluating Instructionally Sensitive Assessments) project builds on the notion of variations in the proximity of assessments to the enacted curriculum (i.e., close, proximal, and distal; see Ruiz-Primo et al. 2002). At a close level, assessments are curriculum sensitive; they are close to the content and activities of the curriculum. At a proximal level, assessments consider the knowledge and skills relevant to the curriculum, but their contexts (e.g., scenarios) differ from the one studied in the unit. At a distal level, assessments are based on state or national standards for a particular domain. Close assessments are assumed to be more sensitive than proximal or distal assessments to the impact of instruction. Proximal assessments are assumed to pose greater demands on students than close assessments; to achieve in these assessments, students need to transfer what they have learned to new contexts – which is likely to happen only if they have received high-quality instruction. Distal assessments tapped learning goals most likely differ from the goals of the curriculum students learned. Large-scale assessments are distal; they are assumed to be less sensitive to the instruction received by students.

The DEISA approach proposes the idea of "bundles of triads" to develop test items. Each triad has one close item and two types of proximal items, one near proximal and one far proximal. (Since distal items are selected from state, national, and international large-scale tests, they have not been the focus of the project, which focuses on test development.) A triad is used to (1) establish, based on information on student performance on the close item, whether the learning of the concept, principle, or explanation model took place after instruction and (2) to manipulate different contexts with the two types of proximal items in a way that some evidence can be obtained on how able students are to transfer their learning as a result of the instruction. Regarding the items' questions, items with different distances to the enacted curriculum are produced through variations on the question they pose, their cognitive demands, and their contexts. Near proximal and far proximal item questions may be less familiar to students, compared to the questions studied in the curriculum, yet they tap the same content or inquiry process. Regarding the items' cognitive demands, near proximal and far proximal items are designed to require students to go beyond what was studied in the curriculum, for example, by requiring students to use a pattern of reasoning that differs from that used in the curriculum activities (e.g., if a science curriculum examines causes of erosion, near proximal and far proximal items may ask about factors that can contribute to reducing erosion). Regarding the items' contexts, near proximal and far proximal items have different scenarios from those used in the curriculum. For example, aspects of the scenarios that are changed may involve organisms, variables, and levels or values of variables.

The DEISA approach has been empirically evaluated through four iterations with different science curricula. Available evidence indicates that the DEISA approach can be used to obtain information relevant to developing items that can be sensitive to the quality of instruction students received.

Information about the content and the quality of instruction to deliver the content was collected through videotapes, interviews, questionnaires, and focus groups. Information based on the PPDI and group comparisons indicates that the approach enables developers to construct items that vary in instructional sensitivity. Remarkably, on average, the effect sizes of the difference between pretest and posttest scores across the tested science modules are consistent with the distance of the items: ES close items = 0.95, ES near proximal items = 0.71, ES far proximal items = 0.30, and ES distal items = 0.41. Results about the pattern linking quality of instructional and students' performance are mixed; different measures of quality of instruction had led to different patterns. These results are consistent with findings from other studies using measures of quality of instruction (see Polikoff 2010).

Importance of Instructional Sensitivity

Accountability tests are largely instructionally insensitive mainly because, due to the sampling procedures used for large-scale testing, very little of what is taught is tested. As a consequence, test results reflect socioeconomic status, general ability, or maturation rather than effective instruction. As Popham and Ryan (2012) suggested, "Clearly, if the tests being employed in these evaluations [to evaluate success of schools] are not up to the job, then many of the resultant evaluative decisions about the effectiveness of schools and teachers will be mistaken. Mistaken decisions about the caliber of schools or teachers, of course, will have both short-term and long-term harmful effects on the quality of education we supply to our students" (p. 1).

Test developers should provide empirical evidence about instructional sensitivity with the same care as it is done for other aspects of validity or of the tests (e.g., discrimination and difficulty). They should plan ahead of time for studies to gather the necessary information. If nothing else, at least statistical approaches to measuring instructional sensitivity should be used (e.g., PPDI and ZDIFF) to provide such evidence.

More research is needed to better determine the link between quality of instruction and student performance. For now, we do know that there is a wealth of evidence indicating that instructional sensitivity is an important characteristic of criterion-reference assessments that, if not met, can threaten the validity of decisions made based on tests.

Cross-References

- ▶ Alignment
- ▶ Opportunity to Learn
- ▶ Test
- ▶ Validity and Reliability of Science Assessments

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Integrated Curricula

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Keywords

Cross-disciplinary; Interdisciplinary; Thematic; Transdisciplinary

Definition

Most curriculum documents around the world are structured around subjects that are derived from disciplines. The subjects provide order and authenticity to the nature and scope of the knowledge to be taught and learned in schools. Curriculum integration is about teaching and learning processes that cross the traditional disciplinary or subject matter boundaries in some way. Integration can occur between broader subjects such as history and science, for example, students could learn about the history of the development of human understanding of gravity. Integration can also occur between closer disciplines within science, for example, students could learn about both mechanics and anatomy through investigations of bird flight. Some curriculum documents highlight the importance of integration, and others ignore it altogether. There are a number of alternative terms that are used to refer to integrated curricula, for example, cross-disciplinary, interdisciplinary, and transdisciplinary. All these terms refer to a curriculum that bridges the boundaries of the traditional subjects in some way. There are a number of educational programs and comparatively new subjects that are inherently integrated. For example, environmental science is a topic that bridges the boundaries of traditional subjects by including subject matter from chemistry, biology, and physics as well as other disciplines including economics and politics.

Approaches to Integrated Curricula

While curriculum documents and schools are most often structured around traditional discipline-based subjects, there are a number of examples of different approaches to curricula reported in the literature that can be considered integrated. An overview as well as an in-depth analysis of case studies of these approaches is presented in Rennie et al. (2012a). Examples of different approaches include a thematic approach, a community-based issue approach, and a problem-based approach. Each of these approaches has something other than the subjects that drives what is taught and learned.

A thematic approach to integrated curriculum is popular in elementary and middle schools. Teachers and/or students select a theme of interest or importance to them around which all teaching and learning activities are organized. Examples of themes might include dinosaurs, the Olympics, and junk food. Teachers plan a number of activities that utilize skills and/or knowledge from a number of subject areas that are linked to the theme in some way. A thematic approach to curriculum often finishes with a special event, like a fair or an open day, where parents and other students and teachers are invited to come and see or participate in the learning.

Another example of an approach to integrating the curriculum is to focus on a community-based issue, event, or locality such as the health and well-being of local indigenous people, the ecology of a local lake or mountain, or a local industry such as a mine site or fishing industry. Through this approach, discipline-based knowledge is used to understand and explore the problem as necessary. For example, considerable chemistry may be used to investigate the solutes in a local lake and the different types of pollution from a local mine site. From a social science perspective, the importance of a lake or a mine site to the people who actually live in the town or city may be investigated.

In high schools, problem-based approaches to curriculum are often used to focus on issues that are of particular relevance or interest to youth. For example, problems such as teen pregnancy, binge drinking, or natural disasters can be the driving force behind the curriculum, and the students themselves may make decisions about which aspect of the problem they will use to develop their knowledge and understanding. Students often plan and conduct investigations in an inquiry-based manner to answer their research problem and then communicate their findings to other members of the class.

The Paradox of Integrated Curricula

The term “curriculum integration” can be considered to be paradoxical when we think about knowledge in our everyday environments. Knowledge outside of schools and educational institutions is not divided up into disciplines or subjects; it is of course integrated. The paradox, therefore, is that when we refer to integrated curricula, we are talking about bringing together something (the subjects) that is in fact always together in the real world. Ever since educational institutions first began, however, knowledge has been divided into compartments so that it was easier to investigate, understand, and communicate from generation to generation. Through a long history, the disciplines have developed great bodies of knowledge, and it is within the disciplines that the most powerful and useful ideas have come to fruition. Each discipline has its own way of understanding knowledge, its own traditions, language, symbols, methods of inquiry, and methods of communication. These factors have enabled disciplines to become authoritative and enduring; however, they remain human constructs.

It is a consequence of the influence and validity of the knowledge available through the disciplines, that the associated subjects provide the structure for almost all curriculum documents worldwide. In almost all school curriculum documents, major subjects include English (or the relevant language), mathematics, history, science, and physical education. Within science, the subdisciplines (biology, chemistry, physics, and sometimes geology and astronomy) are almost always present.

The State of Knowledge in the Global World

The state of knowledge in this age of globalization has resulted in many people rethinking how our curriculum documents are structured and how we can better engage students in learning activities that require them to be able to think and work across disciplinary boundaries. The state of knowledge toward the end of the twentieth- and the beginning of the twenty-first centuries seems to have shifted to more complex, integrated, and holistic issues and problems facing our planet and humanity. These problems and issues are not confined within one discipline, and solutions require people from a number of disciplines to bring their knowledge and expertise to bear. Furthermore, understanding these problems requires knowledge from a number of disciplines. An example of one of the problems is climate change: a global issue that can be informed and understood from a number of disciplinary perspectives including physics, chemistry, biology, geology, history, economics, geography, politics, and so on. Human population growth is another global complexity that may be better understood and informed through multiple disciplinary perspectives. Cutting-edge research also often involves experts from a number of disciplines. For example, advances in forensic science have been driven by knowledge from anthropology, chemistry, computer imaging, geometry, geography, dietetics, and other subdisciplines. Another example is research into endangered species which often involves conservation biologists, geneticists, and ecologists looking at the biological aspects of a particular plant or animal but also mathematicians and computer programmers who can use the information to conduct important population modeling based on a range of variables. It is questionable whether compartmentalized curricula in schools enable young people to appreciate global complexities and cutting-edge research of this nature.

The Dilemma of Integrated Curricula

The current status quo in schools throughout the world is to compartmentalize the subject matter taught and learned into subjects based on disciplinary knowledge such as science, history, mathematics, and English. On one hand, this provides students a wealth of foundational knowledge in highly respected disciplines that are easily examined and are accompanied with high status. Passing discipline-based subjects like physics and chemistry provides students with the power to pass high-stakes entrance exams and gain entry into prestigious universities as well as providing career trajectories into highly remunerated occupations such as medicine, law, and engineering. On the other hand, restricting students' learning to within the disciplines can be considered to prevent their access to powerful ways of thinking that are not available from within one subject. For example, learning to think from different perspectives and in creative ways is said to be enhanced through an integrated curriculum. Learning important facts and information in chemistry about acid rain is one thing, but being able to apply that understanding to real-world contexts and create arguments and debate issues around acid rain extends that learning. Students also are better engaged by a curriculum that is more grounded in the everyday, integrated world and the problems and issues that are relevant to them. Integrated subjects, however, are difficult to define and difficult to assess in quantitative ways. The dilemma with regard to integrated curricula faced by teachers, parents, and students is that learning within the discipline-based subjects is likely to support and facilitate them making rapid progress through the educational pipeline; however, learning restricted to these same subjects is likely to confine their learning to narrowly defined skills and knowledge that is not very helpful or easily applied in the real world.

Student Learning Within Integrated Curricula

Student learning through integrated curricula is more difficult to measure than learning through discipline-based approaches to curriculum. One reason for this difficulty is that students often work independently or in small groups, and their work is idiosyncratic and not uniform across the whole class or the whole year cohort. It is, therefore, inappropriate to test specific types of knowledge when students are engaged in an integrated curriculum because different students often learn different things.

Integrated curricula are not common; therefore, the education community has not necessarily developed the types of tests and assessments that may give a clear indication of the learning that has occurred. For example, students experiencing an integrated curriculum may learn about ratios in mathematics and apply that knowledge to a genetics problem. The transfer process and application to a real-world problem may be something the student has learned; however, it is difficult to test their ability to transfer knowledge in an exam situation.

Another example of the type of learning that is more likely to occur through an integrated curriculum is that students learn to use different sources of information to help them solve problems, as is common in the real world. For example, students may be working on a project for which they need to know how to apply Ohm's law to get the maximum amount of power from that of a solar-powered boat. They may learn that asking their teacher, a knowledgeable friend, or parent for information, accessing information from the Internet or a textbook, and doing their own investigations and trials are all legitimate ways to help them understand these types of processes in the real world. But it is very difficult to test students' ability to use different sources of knowledge, or how they make judgments about the quality of knowledge from different sources in an exam context. Of course this type of assessment is not impossible; it's just much more difficult, less valid, and less reliable than current approaches to discipline-based examinations that educators have developed and trialed over many years.

Other learning that occurs in integrated curricula is said to be less about discipline-based knowledge and more about aesthetics, communication, and collaboration. For example, students may learn how to work with other people who bring different points of view and different knowledge to a problem. They need to be able to communicate with these people and to collaborate and negotiate in order to problem solve and move forward with whatever project it is that they are working on. These types of knowledge and skills are less tangible and less reliable for educators to measure, and this means that in competitive, exam-driven educational environments, integrated curricula often have less value and less status and are considered to inculcate *soft* concepts and *everyday* knowledge.

The perspective that integrated curricula do not contain *hard* or *valuable* knowledge misses entirely the point that through integrated curricula, it is possible for students to learn disciplinary-based knowledge, but in addition, they are more likely to learn the skills that will enable them to apply that knowledge in different contexts. They are more likely to learn to collaborate with people and utilize each other's skills and abilities; they are more likely to be able to think from different perspectives, to weigh up the pros and cons, and to make decisions; and they are more likely to be able to communicate their thoughts and findings to a range of audiences. These qualities may not help students to pass discipline-based exams, but they are much more likely to help young people to develop into better researchers, better employees, better thinkers and decision makers, better communicators, and ultimately better citizens.

The Challenges When Implementing Integrated Curricula

The biggest challenge to designing and implementing an integrated curriculum is that curriculum documents are usually written around the disciplines and are assessed through the disciplines. This means that the content that has to be taught and the various modes of teaching and assessing often are discipline specific. It is difficult for teachers to map the things that students learn through an integrated curriculum onto the discipline-based curriculum documents to ensure that all the contents, skills, and values that students are required to learn have been addressed.

Another challenge when implementing integrated curricula is that high school teachers usually have specializations in one discipline area. Even if they are a science specialist, their own education means they are likely to have strengths in subdisciplines such as chemistry, physics, biology, or geology. Teachers often are uncomfortable teaching outside their area of expertise, and research has shown that when they do, they tend to rely more on traditional, teacher-centered approaches commonly referred to as "chalk and talk."

An integrated curriculum often requires teachers to collaborate with teachers with expertise in another field. In high schools where there are subject-based departments, often in different buildings and on different timetables, collaboration can be very challenging. Extra money often is required to allow teachers the time they need to get together and plan, to change their programs and teaching activities, and also to incorporate field trips and guest speakers. Block time often is required in the school timetable to allow for the nonclassroom-based activities that are frequently part of an integrated curriculum.

Parents, principals, and community members are usually more familiar with the traditional subjects and understand and value them better than subjects that are more integrated. When teachers try to implement an integrated curriculum, it may not be well understood by major stakeholders, and it has been shown that they may disapprove or not look favorably on these subjects.

High-stakes exams require students to memorize a lot of information from a particular content domain, and this forces teaching into narrow aspects of the curriculum and into more teacher-focused approaches. This means that integrated approaches to curriculum are often ignored, particularly around exam time.

One of the major challenges for integrated approaches to curriculum is that due to their very nature, they challenge the status quo of discipline-based approaches to education and the power and status that accompanies discipline-based subjects. Everything to do with education revolves around the subjects. There are subject-based professional learning programs, the architecture of schools is planned and built to accommodate the subjects, teachers are qualified to teach subjects, and school departments are based on subjects. These are powerful mitigating factors that work against the implementation of integrated curricula.

Within schools, the status of discipline-based knowledge is defended and lauded by those who belong to the discipline-based community. Integrated curricula can be seen as a threat to the high status of subjects like science and the subdisciplines of physics, chemistry, biology, and mathematics, for example. Integrated approaches to curricula may be seen to break down the walls that delineate strongly defined areas of knowledge and to erode the identity and status of the people who belong to the discipline-based communities of teachers.

Facilitating Integrated Curricula

One way to conceptualize curricula for the future that addresses many of the concerns raised above is to view approaches to curriculum from a Worldly Perspective (Rennie et al. 2012b). A Worldly Perspective reflects a holistic view of knowledge, grounded in students' experiences, relationships, and contexts. Disciplinary knowledge is an important component of this holistic view, and from a Worldly Perspective, the integrated and disciplinary paradigms should be considered together, overlapping rather than mutually exclusive. A Worldly Perspective encourages educators to balance a discipline-based and an integrated view of knowledge in curriculum. It also encourages connection between local and global themes and issues in curriculum. This balance between integrated and disciplinary approaches to curriculum and connection between local and global themes and issues challenges more traditional ways of making judgments about knowledge and approaches to curriculum. From a Worldly Perspective, the better a curriculum demonstrates these aspects of balance and connection, the more powerful the curriculum, and the more intellectual power it provides to those who have access to it (Rennie et al. 2012b).

While the Worldly Perspective is a powerful way to reimagine curriculum, a number of practical steps also need to be implemented at the school and classroom level to support a curriculum that is consistent with the Worldly Perspective. These practical steps can be put under four broad categories including shared purpose, collegial relations, norms of improvement, and structure. Implementing and sustaining an integrated approach to the school curriculum requires changing the context of schooling and addressing factors in each of these four broad categories. This requires including an integrated curriculum in the shared ideas about the purposeful educational direction of the school and documenting these shared ideas within the school mission and vision statement and other relevant documents and garnering administrative and community support for that direction. Collegial relations between teachers need to be addressed so that mutual sharing, assistance, and joint effort are valued and honored and become part of the normal practice in the school. This may involve the establishment of stable teams or small groups of teachers who work together in a cross-disciplinary way on aspects of the curriculum. Changes need to be made to the way teachers seek to improve their practice, that is, they may have to focus less on feedback from state or national testing results and focus more on outcomes displayed by their students in the classroom context. Teachers need to understand the holistic direction the school is taking, their role within that direction, and they should focus on improving their practice to serve the school vision. Finally, structures within the school need to be changed so that they support the other three conditions. This may involve changing the timetable to give more flexibility, providing time for teachers to work together as teams, rearranging the seating and other work arrangements for teachers and students to better facilitate communication, revisiting assessment and rewards processes, or rebuilding or refurbishing parts of the school or classroom to reconnect with the outside environment and the local community.

Cross-References

- ▶ Authentic Science
- ▶ Context-Led Science Projects
- ▶ Curriculum Movements in Science Education
- ▶ Primary/Elementary School Science Curriculum Projects
- ▶ Relevance
- ▶ Science for Citizenship
- ▶ Science, Technology and Society (STS)

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Integrated Science

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Keywords

Thematic; Transdisciplinary

The term “integrated science” is often used as a synonym for interdisciplinary and unified science, which may be applied generally to any curriculum effort in which two or more previously separated science subjects are combined (Showalter 1975). The effort, according to Brown (1977), may be characterized as a collaboration among, a blending with, or a fusion of a number of “subjects” traditionally taught separately. Thus, the meaning of integration in various types of integrated science is different. An integrated science course may be characterized by a focus on processes of scientific inquiry, or a wish to cater for the interests of pupils, or it may be a course structured around topics, themes, or problems that require a multidisciplinary approach. Brown (1977) identified four groups of meanings of integration in science: (1) as the unity of all knowledge, (2) as the conceptual unity of the sciences, (3) as a unified process of scientific enquiry, and (4) as interdisciplinary study. Examples of each of these meanings can be found in the history of the development of integrated science curricula. *The Conceptually Oriented Program in Elementary Science (COPES)* in the United States, for example, has four conceptual schemes: the structural unity of the universe, interaction and change, degradation of energy, and the statistical view of nature. *Science – A Process Approach*, also from the United States, uses scientific processes as the basis of integration. Integrated science curricula with an interdisciplinary approach often emphasize the interaction between science and society (e.g., *Science and Technology in Society* (SATIS) in the United Kingdom).

According to Blum (1991), there are two clusters of arguments that are used to advocate integrated science at the secondary school level. The first includes epistemological and methodological arguments while the other includes psychological, pedagogical, societal, and practical arguments. For a given integrated science curriculum, there may be a wide range of reasons why it has been chosen in preference to traditional separate science curricula. Brown (1977) also developed a classification system of arguments for integrated science, which comprises six factors: (1) outcomes demanded by society (e.g., provision of scientists, informed lay population, informed political leadership), (2) resource constraints (e.g., accommodation, equipment, time, teachers), (3) political constraints (e.g., common-core course for all pupils, national assessment system), (4) conditions for effective learning (e.g., pupil security, motivation, interest), (5) conditions for effective teaching (e.g., teachers' interests, competence), and (6) constraints imposed by the subject (e.g., unified nature of scientific enquiry). These various arguments are associated with a range of influences and choices which operate at either macro or micro levels in society or both. This classification system can be used to analyze the arguments used for any given integrated science curriculum.

Two dimensions of integration were also put forward by Blum (1991). One is "scope," which refers to the range of disciplines and fields of study from which content has been used in an integrated science curriculum; the other is "intensity," the degree to which the subject matter has actually been integrated. Six categories of "scope" were suggested by Blum (1991): (1) within one of the classical natural sciences (e.g., botany and zoology in biology), (2) between two close natural sciences (e.g., chemistry and physics as physical science), (3) between the natural sciences (and perhaps also mathematics), (4) between basic and applied sciences and technology, (5) between natural and social science, and (6) between science and humanities or arts. Blum suggests that, along with the dimension of "intensity," integration can proceed from "coordination" (independent subject programs taught simultaneously), through "combination" (with major units organized round headings taken from the different disciplines), to "amalgamation" (a particular "issue" forming the unifying principle).

The integrated science curriculum developed in China from the 1980s to the beginning of the new millennium can be used to illustrate the concepts of "scope" and "intensity" (Wei 2009). Aiming to integrate biology, chemistry, and physics in the junior secondary school, this curriculum belongs to the third category of "scope," i.e., "between the natural sciences." The "intensity" of this curriculum was different at its two stages of development. At the first stage, at the provincial level in the 1980s/1990s, the aim was "integration within science subjects." At the second stage, at the national level at the beginning of the new millennium, "integration beyond science subjects" became the aim, and themes that cut across subjects, such as scientific inquiry and nature of science, were used to integrate the curriculum content (Wei 2009).

Cross-References

- ▶ Curriculum Movements in Science Education
- ▶ Integrated Curricula
- ▶ Primary/Elementary School Science Curriculum Projects
- ▶ Relevance

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Intended Curriculum

- ▶ Curriculum

Interactive Exhibits

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Definition and Background

There is general agreement among museum professionals and scholars that the key feature of an interactive exhibit (or “interactive” for short) is reciprocity: as a visitor uses the exhibit, it responds in some way. This distinguishes it from more traditional exhibits that may be read or observed but do not change physically in response to visitors’ actions. The simplest interactives respond in only very limited ways, such as revealing more information to visitors when a flap is lifted or initiating a mechanical process when a button is pushed. More typically, however, interactive exhibits include mechanical, optical, magnetic, or electrical components that can be moved, connected, and adjusted in a broad variety of ways. Interactives often include some kind of interpretive labels that guide visitors and orient them to the goals of the exhibit; these typically include instructions or challenges, questions or hints, explanations, and a connection to daily life. While interactives are often referred to as “hands-on” exhibits by the public, that phrase is something of a misnomer, since even a static exhibit may be available for touching, while an interactive exhibit is truly responsive to visitors’ actions.

Interactive exhibits are not new – visitor-activated models date back at least to 1889 in Germany – but they became widespread in the 1970s and 1980s with the growth of children’s museums and science centers in countries such as Canada and the USA. Since then, they have become common in all kinds of museums and both indoor and outdoor public spaces around the world. With the advent of computer technologies, interactive exhibits have become even more open-ended and adaptable.

Contributions to Science Learning

Various theoretical frameworks have been used to classify and assess the kinds of learning that interactive exhibits seem to support. Among the more common are constructivist theories that characterize cognitive learning, sociocultural theories that emphasize visitors’ participation with others using language and tools, and various psychological theories that focus on affective and motivational dimensions of learning.

In terms of cognition, interactives have shown evidence of contributing to visitors’ understanding of scientific content: particular scientific concepts (such as gravitational force), principles (such as conservation of angular momentum when a spinning person changes her rotational inertia by pulling her arms closer to her body), observable features (such as the structures of genetically modified worms), or the behavior of a system of components (such as the way artificial muscles move the legs of a robot). The way a visitor uses the exhibit can also make a difference: for example, there is evidence that children who play with an interactive exhibit in an investigatory way show greater learning of scientific content goals than those who engage in fantasy play at the exhibit.

Interactives have been shown to elicit a range of scientific and engineering practices, as visitors spontaneously engage in exploring, questioning, investigating, designing, and building. However, such practices are not equally supported: the most frequently observed learning behaviors by visitors are usually action-oriented (such as manipulating the exhibit and seeing what happens), while more reflective behaviors such as generalization, argumentation, and conclusion are considerably rarer.

Research has also shown the importance of human facilitation in aiding learning at interactives. Typically parents will support children, focusing their attention, explaining how the exhibits work (especially often to boy children), and drawing connections to similar real-world experiences as well as formal science ideas. Parents of young children tend to either sit back or take over, so exhibit labels can help by suggesting ways they can contribute and support their children.

Finally, it is well established that interactive exhibits are extremely attractive to museum visitors and tend to sustain their engagement for a longer time than non-interactives. Even in institutions with live animals, visitors often seek and talk about their interactions with the animals; this is a likely contributor to the popularity of touch tanks in aquariums.

Design Challenges

Apart from considerations of greater cost, ongoing maintenance, and safety concerns, interactives are among the most challenging learning materials to design successfully, because they need to work without the presence of a "teacher" who can guide activity and circumvent problems if visitors become lost, confused, or stuck. Typical design tensions include:

- Degree of complexity: Interactives that support deep and extended exploration are often complex or have multiple components, but such complexity may easily confuse visitors when they first use the exhibit.
- Source of authority: The more open-ended an interactive exhibit, the more authority visitors have in creating and interpreting their own experiences. On the other hand, a more limited set of configurations allows the museum to anticipate visitors' actions and create a label that includes canonical science content voiced with institutional authority.
- Target audience: While exhibit designers may have a particular audience in mind, interactives are likely to be used by museum visitors of literally all ages, abilities, and backgrounds. Designing for a particular age or ability level may easily create unintentional barriers to other types of visitors.

Sometimes these challenges have been resolved by creating a hierarchy of salience so that simple actions are obvious at first and others discovered later. Another successful approach has been to segment the functionality of the exhibit into similar stations so that a social group of visitors can each do personal investigations but still be watching and learning from each other (Fig. 1).

What Makes Effective Interactive Exhibits?

Various researchers have created lists of features that support learning at exhibits more generally. For interactives more specifically, some of the key design recommendations (summarized by Gammon, below) include: clear feedback from the exhibit in response to visitors' actions, few control mechanisms and no requirement of a particular sequence for these, control mechanisms that match visitors' expectations (e.g., dials should work either clockwise or anticlockwise), and use of clear and concise labels near visitors' point of attention as they use the exhibit.

Interactive Exhibits, Fig. 1 Multiple stations allow visitors to easily make drawings in the sand on individual spinning disks while also supporting and learning from each other (Photo courtesy of the Exploratorium)

For interactives to deeply engage visitors in lengthy and self-directed inquiry, such as that aligned with Dewey's vision of education in schools, the most successful designs seem to be quite open-ended, with some combination of compelling phenomena, intriguing challenges, and aesthetically beautiful changes or small components that support combination and construction.

Social engagement has been extensively studied as a pivotal means to science learning and an end in itself. With interactive exhibits, just talking with other visitors increases the amount of exploratory behavior and hence greater understanding of the exhibit. When available, skilled facilitation by a docent or other staff member can further extend and deepen learning. For example, with a little coaching in how to generate productive questions and verbalize interpretations of the results, a staff member can coach both family and field trip groups to engage in longer, more collaborative, and more coherent investigations. Staff can also use their conversations with visitors to change the quality of the talk, such as increasing the amount of ecological discussion within a group exploring at a touch tank.

Despite general guidelines such as these, interactives are so diverse in their goals, designs, audiences, and configurations that it is critically important for designers to pilot test them with users during development.

Current Trends

Interactive exhibits are still at the frontier of changing exhibit designs. Among the trends over the last decade are the following:

- greater support for simultaneous use by social groups of visitors (such as large exhibits with several sides and components) rather than a solo individual;
- increasing use in supporting visitors to share their views on an issue (such as projection tables that present an issue and invite visitors to vote);
- more supports for reflection (such as an embedded video camera that asks visitors to create an illustrated story of their experience using the exhibit);
- blurring of boundaries with other types of experiences and media. Examples include

Interactive Exhibits, Fig. 2 Visitors create an immersive geometrical structure (Photo courtesy of the Exploratorium)

Interactive Exhibits, Fig. 3 "Bug Rug" at California Academy of Sciences, where visitors interact with a simulated jungle floor (Photo courtesy of Snibbe Interactive)

including large-scale immersives with embedded interactive components (such as a climbable structure made of movable geometric pieces), interactives created in virtual reality (such as a musical staircase made entirely in Second Life), dioramas with interactive components (such as an animal diorama incorporating touchable fur or the noise-making structure of a rattlesnake), aquariums with touch tanks (supporting handling of live animals in carefully structured ways), or augmented reality focused on social interaction (such as a floor projection of an animated ecosystem that changes in response to visitors' movements) (Figs. 2 and 3).

Interactives are rich drivers of creative learning assessment methods as well, supporting rich data streams of video and audio recordings, interviews, and observations at many scales of space and time. This is probably because their open-endedness and support for group learning mimic the complexity of real-life settings, their use by diverse publics demands excellent interface design, and their hybridization with other forms of multimedia requires the development of multimedia embedded assessment tools.

Cross-References

- ▶ Interactive Science Centers
- ▶ Museums
- ▶ Visitor Studies

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Interactive Science Centers

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The concept of interactive science centers emerged during the 1960s in Europe and North America; many consider that the Exploratorium in San Francisco marked the beginning of this development. Since this time, they have proliferated worldwide and have been recognized as an important source of informal learning. Interactive science centers have several fundamental differences from museums. Museums are concerned with scholarly research and the management and protection of artifacts. Interactive science centers, on the other hand, have always been about experimentation. Unlike conventional museums, they actively encourage their visitors to handle the exhibits. Interactive science centers contain purpose built exhibits, not objects. These custom built exhibits are crafted in such a way as to provide the visitor with a kinesthetic task that concerns and illustrates a scientific principle. The task may involve handling, looking, hearing, or even smelling. Interactive exhibits are frequently very simple, and this is extremely important, as it cannot be assumed that all visitors will be appropriately and equally skilled at manipulating the exhibit and understanding the implications of such manipulation.

The value of interactivity has emerged from research during the 1980s and 1990s in the areas of both formal and informal science learning. In the world of formal education, the growing constructivist movement placed a high value on experiential learning. The belief that science knowledge is constructed through personal experimentation is at the core of constructivist philosophy.

At the same time, however, increasing attention was being paid to the “problem” of the understanding of science by a broader public. Through large-scale surveys, such as those claiming to measure scientific literacy, the public came to be regarded as lacking in their understanding of science. This so-called deficit model (described by Brian Wynne 1991) was important in the late 1980s, because it was believed that enhanced general science literacy would result in greater economic prosperity, greater appreciation of scientific research, and greater participation in democratic decision-making (discussed in Stocklmayer et al. 2001). Thus efforts to bring science to the public through interactive experiences were a natural and timely development. In more recent times, this deficit model has been deeply criticized and subsequently discarded, but its legacy of science centers remains, with modified goals for exhibit interaction which are more about experience and attitudes than "education" (Stocklmayer and Gilbert 2002).

Another important difference between a museum and a science center is that the latter almost always has explainers or "docents." These people play two main roles. They talk with visitors about the activities, explaining the science and encouraging them to reflect on the experience. Explainers put a human face on the science on display. Second, their presence tends to reduce maintenance costs as they keep a watching brief on visitor behavior. In many cases the explainers are drawn from enthusiastic retirees or students.

Because of the limitations of both funds and labor, interactive exhibits tend to be simple. Simple exhibits are cheap to construct and cheap to maintain. The costs of construction and maintenance have resulted in few science centers featuring interactive exhibits in the areas of chemistry and biology, not only because they are expensive to maintain but because of safety issues. Partly because of these constraints, science centers have generally concentrated on ideas taken from physics. Physics provides an almost limitless source of ideas from which to make cheap, simple, and durable interactive exhibits. Translation of these design principles into other disciplines is a contemporary challenge for science centers.

Interactive science centers began to emerge on the world scene in the 1980s, in a very small way. By the first decade of the twenty-first century, however, there were 2,400 centers in seven world regions, visited by almost 300 million people every year. Across the world, science centers have come to share the same status as museums and art galleries, and many are afforded national status. They complement and add to the formal science education experience, usually working closely with the formal sector. The mission of most, however, is not to "educate" in the formal sense. It is to inspire, interest, challenge, and delight visitors and thus affect their appreciation and knowledge of science.

At the Science Centre World Congress held in Cape Town, South Africa, these institutions resolved to:

Encourage the establishment of science centers and museums in parts of the world where they are lacking.

Support a policy of investment in science, technology, and innovation in response to global economic and financial challenges.

Partner with formal education, arts, business, policy makers, and media where relevant.

Strive to address cross-generational science and technology-related problems that are relevant to local, regional, and global communities and to develop programs that allow the general public to contribute actively to the resolution of these problems.

Continue to develop programs that promote awareness of the multicultural roots of science and the value of indigenous knowledge systems.

Continue to develop partnerships to promote science awareness and engagement across cultural, political, economic, and geographical boundaries.

Conduct further research that measures the efficiency and effectiveness of their programs and to act on this information in order to improve their efficiency and impact.

Further promote dialogue between scientists and the general public so that public opinions on science and technology can be heard and incorporated into decision-making processes.

Further promote creativity, invention, and innovation that lead to more sustainable life styles.

Work together to ensure that they share their joint experience and knowledge of the most effective methods of engaging with science and technology with other local, regional, national, and international bodies that promote science and technology awareness.

Cross-References

- ▶ Explainer
- ▶ Indigenous Knowledge

- ▶ Interactive Exhibits
- ▶ Museums
- ▶ Visitor Studies

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Interactive White Boards

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Main Text

The interactive whiteboard (IWB) is an increasingly popular educational technology and can be found in approximately one eighth of all K-12 classrooms worldwide (34 million teaching spaces). IWBs are found in 85 % of UK classrooms, and their prevalence is rapidly increasing in many other countries. IWB technology combines a large, touch-sensitive electronic board with a data projector, specialized software, and a computer (which drives the projector and runs the software). The projected computer image is visible to a class and allows direct input via finger or stylus. Thus objects and texts can be easily moved or transformed by teachers or students, allowing experimentation, revision, and feedback on student work and a wealth of interesting interactions amongst teachers and students. All drawings, screen captures, or other objects can be stored and retrieved in future lessons, allowing for a continuous thread of interactions across many class sessions or even school years. For example, one teacher progressively built up – over six lessons – a representation of the photosynthesis cycle using images of its components, revisiting earlier elements in each subsequent revision (see http://t-media.educ.cam.ac.uk). Comparing artifacts such as concept maps produced at the beginning and end of such a lesson sequence allows a powerful means of illustrating to learners how their thinking has progressed.

The IWB acts as a focal point in many classrooms for interaction with a wide range of digital media resources. These include texts, photographs, multimedia presentations, animations, simulations and models, interactive diagrams, databases, graphs, tables, web pages, audio and video files, etc. Tools provided as part of the IWB software package include those for annotating text, highlighting, drawing, hide and reveal, resizing and zooming, and saving (storing and retrieving) IWB contents. These functions can help to draw attention to salient features of a representation or process. A key strategy is for teachers or students to publicly interpret a display. For example, one teacher introduced the process of gaseous exchange at the alveoli (the primary gas exchange unit of the lungs) by annotating a diagram, animating it, and then describing it to help pupils develop a powerful mental image of a dynamic process. The IWB can be effectively combined with other peripherals such as a document camera (also known as a "visualizer"), where objects placed beneath the camera stand appear on the screen, or even a standard digital camera. Such peripheral cameras can be used to display critique or compare pupils' work or experimental results or to project an image as a task stimulus. A teacher might compare different flowers, for instance, so that students can critique common or disparate features.

While teachers may emphasize "hands-on" use of the IWB by learners as being important for learning, cognitive engagement must also be prioritized. Hands-on use is motivating but can become mundane unless carefully orchestrated. Digital "artifacts" – objects or texts collaboratively produced and manipulated by teachers and learners – can play a pivotal role in supporting learning. For example, a collective representation of the knowledge that is developing in the class can be displayed on the IWB, serving as a rich resource for further teaching and learning. Interaction with digital artifacts can make new ideas available by making them accessible to collective scrutiny and iterative development. These artifacts can be simple constructions; research shows that advanced or "whizzy" uses of the IWB technology are unnecessary for learning.

The IWB is well suited to support interactive teaching (Thomas and Cutrim Schmid 2010), as contrasted with traditional "whole-class teaching" in science, where technology has tended to use computers for demonstration purposes. The IWB offers a fluid "shared communication space" where teacher and students can explore ideas together, pose questions, and reconcile scientific and informal ideas. Different ideas can more easily be juxtaposed, explored, connected, and compared, highlighting strengths and weaknesses. With proper levels of preparation, teachers can use the IWB to support reasoning activities such as visualizing or modeling a science problem or process, planning experiments or projects, and argumentation. The process of helping students respond to peers' ideas can be designed as part of the activity itself, for example, by helping students progressively build up a food chain, each student can add a link in turn and communicate their reasoning. Creating concrete representations of ideas and receiving feedback allow learners to engage in productive reflections concerning their own explanations and others' critical perspectives. In sum, the use of IWBs to develop and support student engagement with such external "knowledge objects" can serve to highlight differences between perspectives and deepen classroom dialogue.

Teachers require professional development in order to learn to use IWBs for such dynamic, collaborative approaches to science instruction. One research team at Cambridge University has developed a multimedia professional development resource to support classroom dialogue using the IWB (http://dialogueiwb.educ.cam.ac.uk) with accompanying book (Hennessy et al. 2014). Teachers learn to cultivate a comfortable and supportive atmosphere for dialogue. Adolescents, in particular, may be quite self-conscious and hence reluctant to come to the IWB.

The advent of remote input devices (tablets, wireless mice) reduces exposure and releases the teacher from the front of the room. This approach of integrating technologies, where students use handheld computers or remote pointers to interact with IWB content, can add new strategies to engage *everyone* in learning activities. For example, students could work on arranging their own paper mini-diagrams that replicate the IWB image (e.g., composing the photosynthesis equation or matching terms and definitions/functions), justifying their own arrangements to peers. One learner could then arrange the ideas on the IWB with others verifying the diagram. Prediction could engage a whole class, e.g., through working with peers to formulate a theory about how the structural features of alveoli facilitate gaseous exchange. The IWB can also act as a focal point for class discussion of displayed observation data, helping students in a variety of different constructivist learning processes for science: noticing and resolving divergence, considering additional avenues for reflection or observation, grouping ideas together to generate insights about a new topic, reflecting on data or hypotheses, brainstorming limitations to current approaches, or proposing new inquiries (Fong et al. 2012). Discussions carefully facilitated by the teacher are essential to support learning.

Finally, new IWB features, technologies, and forms of interaction are emerging. For example, horizontal multiuser "tabletop" boards can support collaborative learning within and between groups (Higgins et al. 2013). Teachers can centrally manage student tables and project them onto the vertical IWB. As ever, educators must harness new tools purposefully. Rather than just another form of "supplemental technology" that is ignored or used for conventional instruction, the IWB can be a transformative addition to the science classroom, if pedagogy is the driving force in its application.

Cross-References

- ▶ Concept Mapping
- ▶ Knowledge-Building Communities
- ▶ Tangible and Embodied Interactions for Learning
- ▶ Technology for Science Education: History
- ▶ Technology for Science Education: Research

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Interests in Science

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Keywords

Interdisciplinary; Student interest in science

How Is Interest Defined?

Generally speaking, interests are perceived as psychological traits that activate individuals to respond to external activities, events, or objects. It is interest that highlights an individual's personal orientation and responsiveness to a particular activity or experience. So how does this translate to student interest in science? According to the Organisation for Economic Co-operation and Development (OECD), the organization that designs and implements the Programme for International Student Assessment (PISA), the student who shows interest in science:

- Demonstrates curiosity in science and science-related issues or endeavors
- Pursues additional scientific knowledge and skills for intrinsic purposes using a range of methods and resources
- Seeks information about science-related careers

Why Is Student Interest Considered Important?

Over the last two decades, student interest in science has become a prime focus of attention as it is often used in educational policy to explain the consistent decline in student uptake of science-related subjects in many countries. Clearly, this trend is economically important for stakeholders given that declining enrolments in science subjects in secondary schooling have a flow-on effect to universities and ultimately the future workforce. Compounding the issue is an opposing trend in some developing countries like India, China, and Korea where students actively seek degrees in science, technology, engineering, and mathematics (STEM) as a means of ensuring a reputable career that provides economic security over the long term (OECD 2008). For many teachers, policy personnel, and educational stakeholders, there is a perception that it is a lack of student interest in science that is causing this decline in the uptake of science in many countries.

What Is Known?

Research does suggest that interest is a motivator for students to undertake deeper thinking and cognitive engagement in a task, activity, or experience. One of the largest international studies to explore student interest in science was the Relevance of Science Education (ROSE) project convened by Svein Sjøberg from Norway. Some of the key data from this study of 14- to 16-year-old students in over 30 countries indicated that students in western countries demonstrated greater interest in science topics that were rarely taught in school (e.g., existence of life outside of Earth), while students in developing countries preferred more traditional topics, such as chemicals, properties, and reactions. Complicating these differences further were significant gender variations that emerged in relation to specific science topics. For example, female students in most countries were interested in topics around health, medicine, the human body, beauty, and aesthetics (e.g., eating to keep healthy and fit), while male students preferred topics that were technical, electrical, mechanical, or volatile in nature (e.g., explosive chemicals) (Sjøberg and Schreiner 2010).

Similar results emerged from the PISA attitudinal survey conducted in 2006 with 68 % of students across 57 participating countries demonstrating greater interest in topics aligned with human biology and less interest for topics related to astronomy, chemistry, physics, and plants. However, what was different with PISA was that 87 % of students with minimal interest in school science topics recognized that science in general was important to society. This point suggests that students distinguish between their interests in school science and science as viewed in the media or in the world around them. As synthesized by Peter Fensham (2006), school science for many students is viewed merely as the transmission of knowledge and content from a textbook having little actual relevance to their everyday lives.

So, what can be gleaned from what is known currently? Clearly, there appear to be some topics in science that generate greater student interest than others, although this does vary between students from western (OECD) and developing countries. Furthermore, there does appear to be a gender preference around these topics, which is more pronounced in some countries. But these variations in student interest are not a recent phenomenon with much of the earlier research in science education identifying similar variations and fluctuations (Ainley et al. 1994; Fraser 1978). The bottom line is that there does not appear to be any substantive difference in the levels of student interest now and 30 years ago.

There is little doubt that interest is a motivator. However, to date there is no causal link evident in the research between students' interests in science (school or science generally) and the likelihood they will continue in science-related pathways, even though there is a perception prevalent in broader society that such causality exists. Research around students' choices in science highlights many confounding factors that influence subject selections at the secondary and tertiary levels of education with interest being only one contributory factor to the decision to engage or not with science.

Cross-References

- ▶ Affect in Learning Science
- ▶ Authentic Science
- ▶ Imagination and Learning Science
- ▶ Integrated Science
- ▶ Science for Citizenship

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Internalization

► Socio-Cultural Perspectives on Learning Science

Internet Resources: Designing and Critiquing Materials for Scientific Inquiry

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Keywords

Collaborative work; Evaluation of resources; Internet; Quality of online resources; Science inquiry

Introduction

In twenty-first century science classrooms, teachers and students are frequently engaged with Internet resources: lesson plans, digital textbooks, various kinds of software, videos, and much more. There is, in particular, a profusion of online resources for the teaching and learning of science. This raises important questions about the design of online resources that are effective and engaging, and how educators can evaluate the quality of items they find. This entry discusses criteria for evaluating such resources in terms of their relevance for science inquiry learning. It presents a set of criteria for evaluating resources, with a focus on the nature of the inquiry tasks that those resources can support and their link to authentic science practices.

Evaluating the Quality of Online Resources for K-12 Science Inquiry

Assessing the quality of online resources for inquiry science learning is a complex matter, which has been studied by science and mathematics education researchers (Linn et al. 2003; Kim et al. 2007; Gueudet et al. 2010; Trouche et al. 2013). The assessment must take into account the ease of use of the resource, and the scientific accuracy of its content, but also its didactic or pedagogical relevance. This paper emphasizes the evaluation of the adequacy of the resource with regard to inquiry-based teaching and learning, as defined by science education research.

A review of the science education research literature reveals the following dimensions for the assessment of the quality of online resources:

- *Appropriate tasks for students*: offering students appropriate environments and tasks to get them engaged in scientific inquiry, addressing students with well-defined tasks to motivate, construct, and refine knowledge.
- *Appropriate language*: the language used in the online resource should be adapted to students' knowledge, and scientific language should be introduced carefully.
- *"Hands-on" elements*: "hands-on" activities are central in an inquiry process and can be proposed virtually.
- *Link to authentic scientific practices*: a goal of inquiry-based science teaching is to provide students with authentic learning activities through problem-based situations.
- *Integration of digital media*: online resources offer the possibility of integrating several technological tools such as simulations tools, modeling tools, videos, etc. Many research works underline the importance of presenting knowledge through a large variety of representations to foster students' learning during their inquiry process.
- *Scaffolding for students*: inquiry-based tasks can be difficult for students, because of the autonomy they require. It is well known that for a teacher, helping the students and preserving at the same time the inquiry is complex. The same holds for an online resource, playing here a part of the role of the teacher.
- *Scaffolding for teachers*: many studies emphasize teachers' lacks of technological, scientific, and didactical knowledge concerning

inquiry-based science teaching. Online resources can offer scaffolds on such issues.

- *Collaborative work for students and teachers*: from a student's point of view, studies outline the need for activities that engage students in pairs or groups to conduct argumentation and construct explanations in science inquiry. From a teacher's point of view, studies underline the importance of giving teachers time for collective activities in order to enhance evolution of their practices and their professional development.

Taking into account these dimensions, the design of an online resource, or the assessment of its quality, will require somewhat different guidelines, according to the context of learning (domain, type of user, etc.). The next section presents several comment aspects that characterize the quality of resources: scientific content, scaffolding offered, and possibilities of collective work.

Scientific Aspects

In addition to matching the desired science content goals, Internet resources should include the following features that are related to scientific content:

- *Clarity of objectives and appropriate tasks*: in order to support students' scientific inquiry, activities and materials must present comprehensible and challenging problems or questions.
- *Rich scientific content*: an online resource can present scientific content in diverse ways: written texts, graphs, diagrams, images, animations, hypertexts, or any combination of those media. It can present recent results of science research, adapted to students' level, or more summary forms of information. In general, a variety of representations of scientific concepts is supportive of science inquiry.
- *Articulation of empirical evidence and concepts*: in order to foster science inquiry, learning materials must enable students to fully experience science concepts within physical and virtual learning environments and to make connections between their understandings and a variety of conceptual models. Activities include critiquing evidence and arguments or comparing solutions.
- *"Hands-on" activities, including virtual manipulations*: many inquiry-based activities allow students to investigate questions using empirical data through direct or virtual experiments and manipulations. Online resources can support data collection, data analysis, dynamic modeling, or experimentation with simulations of scientific phenomena.
- *Introduction to scientific language*: introducing science concepts using a vernacular language before using scientific terms can improve students' science learning and understanding as well as their use of scientific language (Brown and Ryoo 2008).
- *Epistemic value*: the resources must propose situations likely to support the introduction of new scientific concepts.

Scaffolding Aspects

There are important aspects of Internet materials for K-12 science inquiry that are concerned with "scaffolding" student and teachers. Scaffolding is defined as a form of support that allows a user to achieve certain activities or applications that might otherwise be out of reach (Quintana et al. 2004).

Many ICT resources include scaffolding for student learning as a matter of design. The following aspects of scaffolding should be considered in evaluating such resources:

- *Conceptual scaffolds*: the resource should provide different representations (formulas, figures, animated pictures) that support "sensemaking" and conceptualization.
- *Strategic scaffolds*: in order to manage their scientific inquiry, students need to understand the ways scientists approach and solve problems in their disciplinary fields. Strategic scaffolds help them determine how and when the resource could be used for inquiry.

- *Procedural scaffolds*: the resource must provide structure and support for complex tasks and functionality, embedding guidance to allow students to succeed with minimal errors.
- *Metacognitive scaffolds*: students may benefit from support to engage in reflection and assessment of their investigations, allowing them to monitor their own progress and develop an accurate sense of self-efficacy.
- *Argumentation scaffolds*: argumentation scaffolds help students justify and evaluate their ideas, potentially for purposes of discussion or debate with peers. Activities that engage students in "talking science" (Lemke 1990) are an important part of IBST.

The criteria mentioned above are also relevant for teachers, who can take cues from the student scaffolds. In addition, the following aspects are directly relevant to supporting teachers as they develop lesson plans or enact them in classrooms:

- *Analysis of inquiry*: an important aspect of support for teachers is concerned with a thoughtful analysis of the materials (with a specific focus on the precise knowledge at stakes), conducted by their designers, concerning how students may understand, misunderstand, or make effective use of the materials. Such analysis could be provided as a supplement (i.e., "for teachers only") to the materials.
- *Discussions of K-12 applications for learning and assessment*: a resource can include some discussion for teachers about how students may work with the resource during the different parts of the lesson (individual work, group work, precise role for each student), time management, and expected output from students (on the computer and on paper). Easy access to student work is essential for the teacher, as well as a discussion of assessment norms and practices.
- *Lesson plans and starter activities*: the way that teachers introduce a resource or activity to students can have a serious impact on its likelihood of success or efficacy. Ideally, resources should contain some discussion about how they should be introduced, in terms of strategies for engaging students in the task, problems or misconceptions that may be encountered, and so on.

Scaffolds for teachers can take diverse forms, including supplemental pages, teacher communities and social networks, or videos of classroom enactment. Classroom videos are helpful, if they are associated with appropriate indications about what can be drawn from these videos.

Collaborative Aspects

Two kinds of collaborative aspects contribute to the quality of a resource for science inquiry. First, the resource should permit or support collaborative work of students and teachers. Second, students or teachers should be able to contribute to the further design or content of the resource.

- *Collaborative work of students or teachers*: an online resource can include recommendations or supports for collaboration among students, interactions with teachers, or even interactions with scientists. Collaboration supports can be synchronous or asynchronous, including discussion forums, wikis, annotations, or other collaborative features. Resources can also support the organization of student groups or the collaboration of teachers with students, peers, teacher professional development specialists, or scientists. Supports for collaboration can include schedules, prompts, or tools (e.g., online discussions) as well as scaffolds to support the use of those elements (e.g., a set of common vocabulary that supports discussions of a lesson).
- *Contribution of the users to the design of the resource*: some online resources provide students with the possibility of integrating their contributions, through votes, tags, or elaborations, into the resource itself. For example, they might submit an inquiry report online,

which could be shared with other users of the resource. They might also add votes, comments, Web links, or other scientific resources. Teachers could add to a resource by contributing lesson plans, opinions, or suggestions that could inform other users or the resource designers.

Conclusions

As the Internet matures from a static resource of links and “pages” to a more dynamic, social environment where users contribute content (e.g., Wikipedia, YouTube) or network socially, there will be new forms of online resources for science inquiry and new opportunities to support K-12 students and teachers. The various qualities delineated here should serve science educators in their efforts to design, develop, evaluate, and apply such resources.

Cross-References

- ▶ Digital Resources for Science Education
- ▶ Inquiry as a Teaching Strategy
- ▶ Inquiry, Learning Through
- ▶ Online Inquiry Environments
- ▶ Online Media

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Interpretive Centers

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Keywords

Nature center; Science centers; Visitor center

Interpretive centers are informal education venues in which a place of interest such as a state/provincial park, wildlife preserve, historic building, or archaeological site is designed to afford the general public an opportunity to better understand the natural or cultural heritage of the site. Interpretive centers are site-specific linking *place-based* educational approaches with public informal learning settings. Often the interpretive center, sometimes referred to as a visitor center, utilizes a variety of approaches to public understanding including diverse media such as video displays, instructional kiosks, interactive computer simulations, or movie theaters. Often center employees such as park rangers, curators or natural resource managers conduct interpretive education programs for visitors. It is not uncommon for centers to include souvenir or gift shops. Nature centers often have a visitor or interpretive center dedicated to educating people about nature and the environment. In addition technological, engineering, or science research sites may have a public visitor/interpretive center for public outreach. They seek to educate and raise awareness of their innovative activities. As such, interpretive centers are very accessible to the general public in urban, suburban, and rural areas and often attract tourists visiting an interesting geographical or historical area.

The original characterization of interpretive centers is as a site for communication to enhance understanding of heritage and create meaningful links of intellectual and emotional connection to natural and cultural resources. This traditional view of the centers derives from Freeman Tilden's *Principles of Interpretation* (Tilden 1957) focusing especially on relating content in meaningful ways to the visitor's own experience leading to emotional connection, thought, and further questions about a subject or site. This perspective is closely aligned with cultural heritage interpretation.

A more recent conceptualization of interpretive centers in the context of natural science education is a place of informal science learning (Committee on Learning Science in Informal Environments 2009) where all ages of people come to spend time in *free-choice learning* activities. Informal science learning settings similar to interpretive centers include museums, aquaria, zoos, botanical gardens, and science centers. Recent innovation in museum programs has led to science centers where interactive, hands-on exhibits may encourage visitors to experiment and explore and interpret the content or site in their own context and experience. The research and educational practice related to interpretive centers and science education is blended into the diverse types of informal science learning environments.

On one end of the informal learning spectrum are visits to parks or gardens where there may be no specific educational structure or agenda for the visitor. In the broad and diverse informal learning context, we also see the organized and planned nature of museum dioramas or interactive exhibits focusing on educating the public about a specific or narrow set of concepts. Interpretive centers and their education programs are found somewhere between these two ends of the informal learning environments spectrum and thus are influenced and informed by the work in both unstructured and structured informal settings.

In the modern context of interpretive centers as informal science learning environments, recent efforts have been made to better understand the nature of learning activities that occur there to better inform design, delivery, assessment, and evaluation of interpretive programs. Much of this work is in the form of evaluation reports on specific programs and is reported as part of education program evaluation literature.

Typically the audience for interpretive centers is the general pubic, however, we often see educational programs targeted at more specific groups such as after-school and camp programs for children or topical programs for adults with special interests. In these contexts, science learning is seen as a dynamic interaction of both formal and informal learning across people's life span.

Because interpretive centers must address the needs of the general public, issues of population, class, race, diversity, socioeconomic status, and special needs are addressed in research and professional-related literature. Interpretive center programs are typically designed for all ages but may be adapted for narrow age groups such as preschool or elder hostel programming. This connection of interpretive centers to diverse audiences and their needs helps to inform science education in general.

The research literature related to interpretive centers is found in a diverse collection of journals, reports, books, and other online literature well beyond the typical science education literature. Journals addressing museum programs and informal learning often include articles related to interpretation. There are professional journals addressing studies of visitors, learning environments as well as interpretation. Journals focused on environmental education also include topics related to interpretive centers.

Research around interpretive centers has been strongly influenced by the free-choice learning (Falk and Dierking 2002) literature. Originally focusing on describing the nature of the experience of visitors/learners, recent research has advanced our understanding of the personal and social aspects of informal learning over time. This ecological view of learning has proven beneficial in understanding the holistic nature of learning in and around interpretive centers.

As in most of science education, the future of interpretive centers will be influenced by the nature of emerging teaching and learning technologies, especially as they relate to public audiences and the delivery of educational programming through portable devices.

Cross-References

- ▶ After School Science
- ▶ Aquaria
- ▶ Botanic Gardens
- ▶ Environmental Education and Science Education
- ▶ Environmental Teacher Education
- ▶ Excursions
- ▶ Learning Science in Informal Contexts
- ▶ Museums
- ▶ Out-of-School Science
- ▶ Science Exhibits
- ▶ Visitor Studies
- ▶ Zoological Gardens

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Interventions, Gender-Related

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Beginning with Alison Kelly's (1985) research, scholars have identified and practitioners have implemented interventions that address girls' interest in, attitudes about, and success in science. Originally, gender-related interventions addressed equity issues in curriculum and in classroom interactions. Early interventions were based on Mary Budd Rowe's (1986) studies of *wait time* and *tinkering time*, on Kenneth Tobin and James Gallagher's (1987) identification of *target students*, and on Kelly's analysis of gender differences in spatial ability. Curricular materials that are focused on relationships as well as rules involve people as well as machines; use pragmatic, not dogmatic, approaches; view the world as a network, not a hierarchy of relationships; emphasize the aesthetic as well as analytical aspects of science; and focus on nurturing living beings as well as inanimate things are gender-related interventions (Small 1984).

Inquiry instruction is an intervention that enhances the achievement as well as the interest of all students in science. Inquiry in science classrooms is defined by engaging with authentic problems, raising appropriate questions, using evidence, justifying claims, and applying appropriate representations (Battey et al. 2007).

Gender-related interventions have moved from ones that address covert actions or materials to more subtle ones such as *gender-related incidents* and *gender lore*.

Cross-References

- ▶ Attitude Differences and Gender
- ▶ Attitudes, Gender-Related
- ▶ Gender
- ▶ Participation, Gender-Related
- ▶ Sociocultural Perspectives and Gender

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Investigation, Assessment of the Ability to

▶ Inquiry, Assessment of the Ability to

Iran

▶ Science Education in Iran

J

Japan, Science Education in

► Kansatsu
► Lesson Study Research and Practice in Science Classrooms
► Rika

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Kansatsu

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Keywords

Incommensurability; Science education in the non-West; Worldview

Traditionally, Japanized Buddhism developed meaning for the term "kansatsu" over more than a thousand years. In this context the most reasonable English translation of the term is "contemplation" that strongly implies empathy with objects (Kawasaki 2002). However, this Japanese term "kansatsu" acquired an additional meaning in the context of learning science in the second half of the nineteenth century as Western scientific ideas came into Japan. Since then, science educators have simply assumed that "kansatsu" is identical with "observation." However, that assumption produces a clear complication because the meaning "observation" conflicts with the meaning that "kansatsu" already has in the Japanese language. The source of this complication lies with Japanese science educators having little understanding of language-culture incommensurability induced by the assumption. In brief, the assumption originates in their ignorance about the arbitrary nature of linguistic signs (Culler 1988, p. 19). If Japanese science educators realize the assumption they are making, they will be able to find a way to overcome the complication and then to minimize it.

In this entry, the complication and a way of overcoming it are briefly described. The description will be applicable to non-European communities where science education is based on the translation of scientific concepts from European languages into students' first and non-European languages (Kawasaki 2010).

In Japan science education is conducted in the Japanese language, which is both students' and teachers' first language. In this language setting students inevitably understand "kansatsu" according to the context of the Japanese language. Moreover, owing to science educators' assumptions of equivalence with "observation," very few of them realize the contradiction between the acquired and the original meanings or the incommensurability between "kansatsu" and "observation." Thus, it is almost impossible that "kansatsu" conveys what "observation" originally means in English contexts in the science classroom.

As indicated in the foregoing, "kansatsu" is no more "observation" than "contemplation" is. The term "observation" leads observers to objectify objects, whereas "kansatsu" connotes empathy with objects. These outlooks on objects are opposite to each other.

This incommensurability reflects differences between the Western scientific and the Japanese worldviews. As a general rule, a worldview is

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potential and a social system of norms: what outlook on this world people should have in their community. As is well known, the Western scientific worldview is based on the dichotomous worldview, which opposes the world of ideas against the phenomenal world, to use Platonic terms. The term "observation" signifies the first step to bridge the gap between these two worlds. In such intellectual activities, scientific objects are objectified (Kawasaki 2002).

By contrast, "kansatsu" acquires its meanings from the Japanese worldview. This worldview has never established such a dichotomous position (Kawasaki 2002). When science teachers use "kansatsu" without realizing the incommensurability, students accept it as a Japanese term and then learn the outlook innate in "kansatsu." Consequently, they cannot conceive "observation." In addition, owing to their assumption, science educators cannot realize this discrepancy. What actually happens to the science classroom in Japan is far from being scientific: Science teachers remind students of what "kansatsu" traditionally signifies and stimulate students to have empathy with their scientific objects.

A strategy for overcoming the complication is not difficult: science educators' awareness of the difference in worldview needs to be raised. However, there is difficulty in implementing this strategy. The curriculum for prospective science teachers in Japan has excluded goals and content aimed at cultivating a comparatist mind and epistemological reflections on what is unwittingly known, what is unwittingly known about "kansatsu" in the present case.

If the comparatist mind was so cultivated, science teachers would be much more likely to understand "kansatsu" against the backdrop of "observation." This understanding would liberate science teachers from confusing "observation" with "kansatsu," and it would become possible for students to develop an appropriate understanding of "observation" that symbolizes the scientific way of thinking, then science.

Science teachers' explanation of the incommensurability can be properly called metalanguage if it is accepted that a language entails a worldview inherent in the language (Kawasaki 2010). An issue that needs discussing in science education research in Japan is the way to enrich such metalanguage. However, science educators are still unaware of the incommensurability because of a widespread lack of a comparatist mind or an understanding of the arbitrary nature of linguistic signs.

It is also very significant to examine the collocation of "kansatsu" with another Japanese term "shizen" translated as "nature." Just as "kansatsu" conveys a critical meaning in the Japanese belief system, so "shizen" conveys another critical meaning – in the Japanese worldview the word refers to "supernatural" (Kawasaki 1996). So clearly, when science teachers use the word as meaning "nature," they are causing the same complications for and confusions in students. And then further complication comes from science educators using the phrase "shizen no kansatsu" to mean the same as the English phrase "to observe nature." Regardless of this incommensurability between the two phrases, science educators have accepted, without comparatist mind, that the phrases are identical.

It is not difficult to envisage the confusion stemming from the science educator belief that the phrases are identical. On one hand, the English phrase encourages the objectifying of natural things and the careful watching of them; on the other hand, the Japanese phrase encourages having a form of mystical empathy with the supernatural embedded in natural things in contemplating them.

This science educator belief characterizes "rika," a Japanese counterpart of school science, and keeps students away from a real understanding of scientific concepts. Conversely, this situation implies the way to minimize the complication. If science educators can realize that foreign language education is filled with metalanguage, the following slogan well expresses the way to overcome the complication: Science education should be associated with foreign language education (Kawasaki 2010).

Cross-References

- ▶ Cultural Imperialism
- ▶ Observation
- ▶ Rika
- ▶ Worldview

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Knowledge About and Understanding of Science, Assessment of

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Assessing students' science learning with respect to knowledge is done for a variety of purposes: formative, summative, and for accountability purposes (Bell 2007). It is the purposes for generating the assessment data which determines what kind of assessment task will be used. For example, written examinations and tests are most often used for assessment of science knowledge learning for summative purposes, as this produces a storable record. Oral conversations between teacher and student are often used for assessment of scientific knowledge for formative purposes, as the feedback and feedforward can be given while the student learning is occurring.

A key aspect of assessing students' learning of scientific knowledge is to assess the extent to which students are able to use their newly acquired knowledge in situations other than the ones in which they learned the knowledge. The distinction between recall of knowledge and the use of that knowledge is made. For example, if students learn about the concept of food chains in the context of the backyard vegetable garden, to what extent are they able to use their newly constructed knowledge to answer assessment questions on food chains in the wild or in the marine environment, as well as in the vegetable garden?

Assessing students' knowledge of science may also be an assessment of their competence in using the science knowledge to reason and solve problems. For example, if the students have learned the science knowledge that one categorizing characteristic of insects is that they have six legs, can the students use this knowledge to decide if a worm, butterfly, centipede, spider, and crayfish/lobsters are insects or not?

The communication format of the assessment tasks may be oral, written with pen and paper, or online using ICT technologies, such as computers, iPads, and iPhones. For example, assessment of knowledge for formative purposes is often done orally in classroom teacher and student conversations. Assessment of science knowledge learning using multiple choice tests may be done online.

Assessing students' science knowledge learning may be done using a variety of assessment tasks (New Zealand Ministry of Education 2012):

Multiple choice tests
Open-ended question items, asking for the student to describe, discuss, explain, and draw
Matching exercises
Essays
Questionnaires
Predict-observe-explain tasks
Completion tasks
Observation of student work books or small group discussions
Interviews
Conferencing
Performance tasks

Projects
Posters
Portfolios of student work
Laboratory reports of practical work
Brainstorming
Concept maps
Puzzles
True-false statements
Student questions
Student learning journals, blogs
Student presentations
Problems solving

When teachers design an assessment task, the following need to be taken into account (Atkin et al. 2001):

- What learning goal is being assessed?
- What criteria will be used to judge the quality of the student work?
- What are the quality indicators of validity and reliability or trustworthiness
- Is it a group or individual assessment task?
- Is this assessment equitable, that is, can all students attempt the assessment or are they restricted by, for example, disability, culture, and gender?
- What kind of data does it give? How will the assessment data be recorded and analyzed? And by who?
- How long will it take to administer? That is, how manageable is it?
- What kinds of teacher judgements are needed to make sense of the data analysis?
- Will the assessment data analysis give you information about what to do next to further increase student learning?
- Is moderation appropriate?

When choosing an assessment task from government or commercial banks of assessment resources, the following additional concerns need to be addressed:

- Country and/or culture of origin, that is, which curriculum is the assessment task aligned with?
- Is the assessment task standardized and norm-referenced for students in your country?
- How much training is needed before it can be used?

Cross-References

- ▶ Assessment: An Overview
- ▶ Authentic Assessment
- ▶ Facts, Concepts, Principles, and Theories in Science, Assessment of: An Overview

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Knowledge, Acquisition of

▶ Metaphors for Learning

Knowledge-Building Communities

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Keywords

Collective inquiry; Knowledge building; Knowledge communities

Main Text

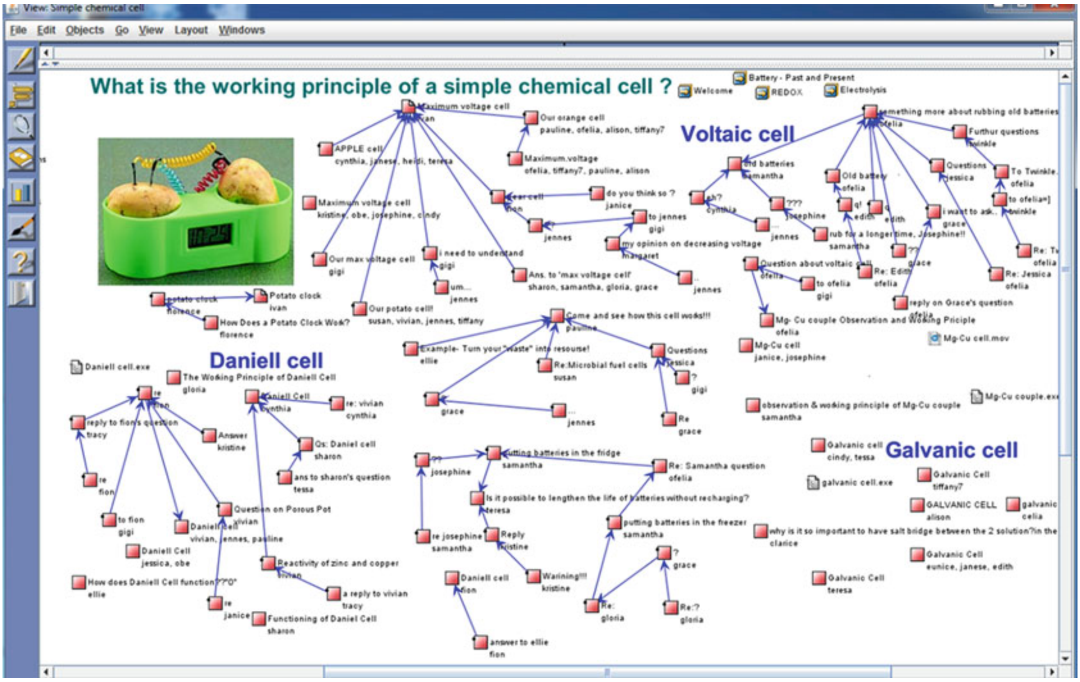
In recent decades, it has been the goal of many science curricula and projects to develop inquiry-based learning in science classrooms. Many such projects, often of short duration, involve students' learning from inquiries and investigations, exploring science phenomena firsthand, carrying out experiments, practicing scientific skills, and applying scientific ideas in new situations. However, critics have pointed out that these approaches fall short of what scientists actually do, as theories emerge within a sustained community of inquiry and knowledge exchange. In classrooms, scientific inquiry is often limited to sequenced activities designed to meet predetermined goals and fixed standards, rather than helping students to develop authentic scientific practices within a community of their peers.

What Is the Knowledge-Building Community Model?

The model of Knowledge-Building Community, developed by Marlene Scardamalia, Carl Bereiter, and colleagues, takes a different approach by focusing student inquiry on the challenge of collectively advancing the knowledge of their community. Knowledge building, the "production of knowledge that adds value to the community" (Scardamalia and Bereiter 2003, p. 1370), fosters the kind of productive knowledge work found in scientific communities, foregrounding the *discourse* by which lines of inquiry are set, explanations are proposed and tested, and the community's overall progress is evaluated. Knowledge building is fundamentally concerned with ideas, particularly the *improvement of ideas*, in a community. In knowledge building, students contribute their ideas to a public space – a computer-supported collaborative learning environment called Knowledge Forum® – where they become shared objects of inquiry, investigations, and progressive discourse. Much like how scientists generate new knowledge, science students can develop the capacity to create and improve ideas that add value to the community. For example, they may formulate problems and put forth ideas, propose an explanation for a given phenomenon, suggest how their idea may be related to other ideas, or how an idea can be tested and modified in building a more coherent theory.

Knowledge building generally refers to how students co-construct knowledge and understanding via discourse, and KBC draws several distinctions among elements that commonly occur in similar community-based models. First, a distinction is made between learning – changes in students' mental capacities and personal understanding – and knowledge building, the improvement of public knowledge (Scardamalia and Bereiter 2003). If learning is a practice in which a community's intellectual heritage is *passed on* to a new generation, then knowledge building *extends* that intellectual tradition. As Scardamalia and Bereiter (2006, pp. 97–98) put it, students in KBCs "come to see themselves and their work as part of the civilization-wide effort to advance knowledge frontiers." When considering students as engaging in a "knowledge-creation culture," it is important to underscore that students are not expected to make new major discoveries, but they can and do engage in knowledge-creation dynamics and regularly make discoveries that are novel in their communities and go beyond what is contained in the sources they study and school curriculum.

A second distinction is made between "belief mode," which emphasizes *argumentation*, and "design mode," which focuses on *progressive problem solving*. While argumentation is currently central to science education, the KBC model postulates that in addition to helping students make claims, justify their beliefs, and use evidence, science educators can also incorporate "design-mode" thinking, as is common in scientific communities. Design mode helps students to view ideas as conceptual artifacts (similar to scientific inventions), which can be continually improved upon by themselves and others. Designing is an open-ended activity, in the sense that it does not have an obvious endpoint but rather serves to advance collective knowledge to a state that is more coherent and powerful in explaining science phenomena. By contrast, belief-mode discourse is more closed and commonly oriented toward persuading others of the merit of an idea, without necessarily improving the idea itself. The KBC model



Knowledge-Building Communities, Fig. 1 A Knowledge Forum view for collective inquiry and scientific discourse

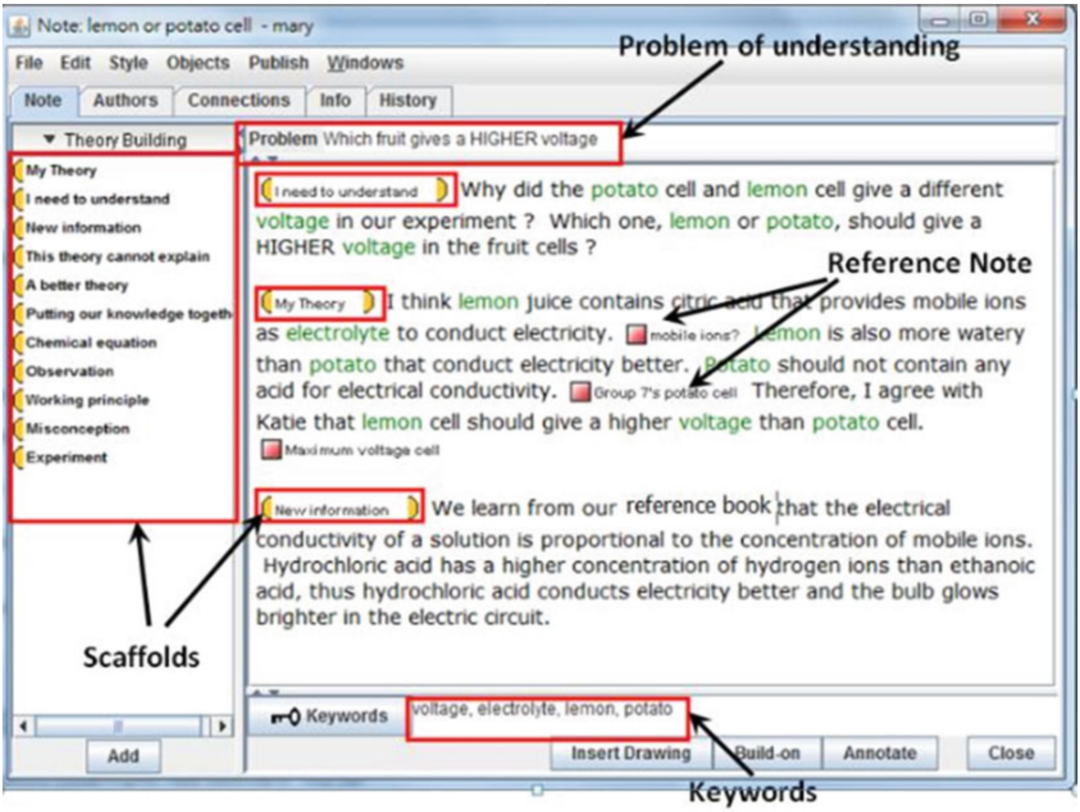
focuses on design mode for theory building to help students engage in the complex processes of knowledge creation. Thus, knowledge building goes beyond merely helping students to develop conceptual understandings, by engaging them in the creation of new knowledge within a community context.

Pedagogical and Technological Support

Technology environments help to support knowledge building by maximizing student agency and empowering students to take up collective cognitive responsibility in advancing their community knowledge. In a typical knowledge-building classroom, students record and work their ideas using Knowledge Forum, including online and offline discourse in which they formulate problems (e.g., "Why do leaves fall?"), propose theories, identify relevant information, construct explanations, and examine different models to help them revise their theories. Working with their teacher, students may conduct experiments to test hypotheses, read to understand difficult information, engage in "knowledge-building talks" to tackle problems emerging from the discourse, and work collectively to advance their theories. Knowledge Forum thus serves as an objectification of the community's advancing knowledge. Using networked computers, students can simultaneously add notes to the database, search or comment on existing notes, or organize notes into more complex structures.

Unlike online forums for discussion or information sharing, Knowledge Forum is designed with the explicit epistemic commitment to help students advance their ideas and focus on *idea improvement*. Features of Knowledge Forum include:

- *Views and notes*. A *view* is a communal area for collective inquiry where students post their questions and ideas and others will "build on" as initial ideas are advanced (Fig. 1). *Notes* can be placed on the view, where lines between the note icons indicate interactions, and students can navigate across different views.



Problem Which fruit gives a HIGHER voltage

I need to understand Why did the potato cell and lemon cell give a different voltage in our experiment ? Which one, lemon or potato, should give a HIGHER voltage in the fruit cells ?

My Theory I think lemon juice contains citric acid that provides mobile ions as electrolyte to conduct electricity. 🟥 mobile ions? Lemon is also more watery than potato that conduct electricity better. Potato should not contain any acid for electrical conductivity. 🟥 Group 7's potato cell Therefore, I agree with Katie that lemon cell should give a higher voltage than potato cell.

🟥 Maximum voltage cell

New information We learn from our reference book that the electrical conductivity of a solution is proportional to the concentration of mobile ions. Hydrochloric acid has a higher concentration of hydrogen ions than ethanoic acid, thus hydrochloric acid conducts electricity better and the bulb glows brighter in the electric circuit.

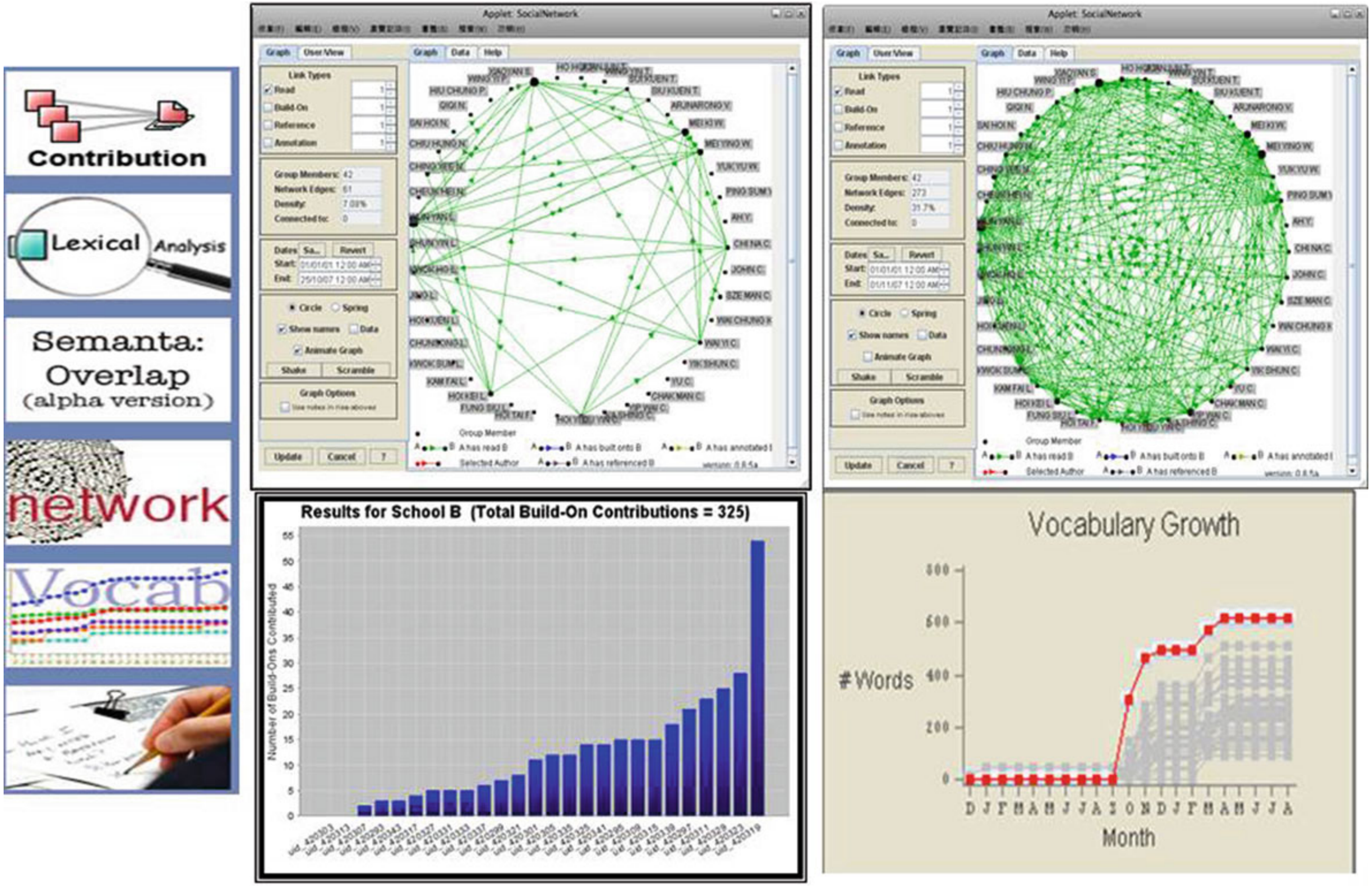
Keywords voltage, electrolyte, lemon, potato

Knowledge-Building Communities, Fig. 2 A Knowledge Forum note with features to support metacognition

- *Metacognitive prompts*. These are scaffolds that help students frame their ideas, during note writing, such as: "I Need to Understand," "My Theory," "New Information," "A Better Theory," and "Putting Our Knowledge Together" (Fig. 2). Students may also use the *problem* tag to highlight their note as being problem centered, and *keywords* for domain vocabulary and search.
- *Linking and rising above*. Tools that help make conceptual progress visible include the opportunity to link views and to create *rise-above views* for emergent questions. When writing notes on Knowledge Forum, students can create *rise-above* notes or add other notes as *references*, much as scientists use references to build on existing ideas and create an integrated web of ideas.
- *Assessment tools*. These have been developed to support students and teachers, including applications that generate information about contribution, social networks, vocabulary growth, and idea improvement (Fig. 3).

International Research

Since the 1990s, the KBC model has been implemented in primary and secondary science classrooms in some 20 countries, illustrating how elementary children can engage in a knowledge-creation approach, how maximizing student agency can bring about knowledge creation, and how principles, rather than scripted activities, are key to emergent knowledge work and sustained classroom innovation (Zhang et al. 2009). The KBC model has also been successful in Asian secondary classrooms despite their emphasis on high-stakes examinations, where teachers have adapted the KBC model to allow students to



☑ Read
☐ Build-On
☐ Reference
☐ Annotation

Group Members: 42
Network Edges: 61
Density: 7.08%
Connected to: 0

Start: 01/01/01 12:00 AM
End: 25/10/07 12:00 AM

● Circle ○ Spring
☑ Show names ☐ Data
☑ Animate Graph

☑ Read
☐ Build-On
☐ Reference
☐ Annotation

Group Members: 42
Network Edges: 273
Density: 31.7%
Connected to: 0

Start: 01/01/01 12:00 AM
End: 01/11/07 12:00 AM

● Circle ○ Spring
☑ Show names ☐ Data
☐ Animate Graph

Knowledge-Building Communities, Fig. 3 Assessment tools: Note-reading density in two periods (*top*); note build-on contribution (*bottom left*), and vocabulary growth (*bottom right*) examine core curriculum ideas, pursue lines of inquiry that arise from their difficulties in understanding the curriculum, synthesize fragmented ideas for rise-above, and use assessment to foster knowledge building (van Aalst and Chan 2007).

Implications for Science Education

The KBC model, in line with National Science Education Standards in the USA and other countries, focuses on scientific literacy and inquiry beyond the simple acquisition of knowledge, processes, and skills. Specifically, the KBC model advocates an agenda for developing a -knowledge-creation culture in science classrooms. In contrast to conventional lecture, laboratory experiment, and inquiry approaches that focus on structured activities, KBC advocates scientific epistemology and commitment, sustained pursuit of idea improvement, theory building, progressive discourse, and collective growth. This emphasis on epistemology aligns well with increased recognition of the importance of students' understanding of nature of science.

Inquiry-based approaches like KBC face many challenges, including the current K-12 science standards that result in curriculum sometimes described as being a "mile wide and an inch deep." Ultimately, applying the KBC model in science classrooms is a matter of fundamentally shifting teachers' and students' epistemological understandings. Substantial research and development has progressed among a widening community of researchers and practitioners, resulting in advances in the pedagogical, technological, and social infrastructure for KBC.

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Laboratories, Teaching in

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Keywords

Affective value; Experiments; “Hands-on”; “Minds-off”; Open-ended investigations; “Recipe” style tasks

One of the features of science education that sets it apart from most other subjects taught in school, perhaps the distinctive feature, is that it involves practical lessons that are, in general, undertaken in specifically designed and purpose-built laboratories. Yet although teaching in the laboratory is widely used in many countries (Lunetta et al. 2007), its educational value remains unclear, with any agreement on this being dependent upon the term “educational value” remaining very loosely defined. Indeed, despite teaching in the laboratory being both widespread and well established (Bennett 2003), research findings regarding its effectiveness in terms of developing conceptual understanding, practical skills, as well as its affective value remain, at best, ambiguous (Abrahams 2011).

However, if, as Plato suggests, the world can be divided into a world of ideas and a world of physical realities, then there is a broad consensus that a fundamental purpose of laboratory teaching in school science is to help students bridge the divide between these two disparate worlds. In essence, effective laboratory teaching provides a link that enables students to understand the world around them in terms of abstract scientific ideas.

Yet teaching in laboratories is not a single, clearly defined, process but rather involves various strategies that include experiments, investigations, discovery, and “recipe” style tasks, all of which can be referred to under the broad overarching heading of “laboratory work” (or “labwork”). Here, the essential difference between the different strategies can be thought of in terms of the degree of “openness” or “closure” of the task – that is, the extent to which decisions regarding the activity are made by the student and/or the teacher. At one end of this continuum are closed “recipe” style tasks in which the teacher sets out what is to be done, how it is to be undertaken, and how the data are to be collected, analyzed, and presented. At the other end of that continuum are open investigations in which students determine what they want to investigate, how they will carry out the task, as well as deciding upon the data to be collected and how this data will be analyzed and presented.

While open-ended investigations do occur in school science lessons, much teaching in school laboratories regularly involves the use of recipe style tasks in which students, generally working in small peer groups, follow a combination of teacher and/or task instructions. This widespread use of recipe style tasks appears to owe more to

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the relatively short nature of most practical lessons and the fact that teachers often want to ensure that their students successfully produce and see the desired phenomena rather than a belief that open-ended investigations might be less effective in developing conceptual understanding or specific practical skills. Another possible reason for the frequent use of recipe style tasks is that teachers' preferences for various types of practical work are informed by curriculum targets and the associated methods of assessment. At present, the skills that those types of investigations develop are not sufficiently recognized in the current assessment criteria to warrant their widespread use.

In an ideal situation all teaching in the laboratory would be synonymous with learning in the laboratory, but, to a certain extent, much laboratory teaching focuses far too narrowly on the unthinking production of a particular phenomenon and/or data set. As a consequence a substantial proportion of teaching in the laboratory can be categorized as "hands-on" but "minds-off." Indeed, many teachers are seemingly still convinced of the merits of the, by now largely discredited, "discovery-based" approach to learning in which "doing" with, and "learning" about, ideas are seen to emerge of their own accord simply from the successful production of a phenomenon. Indeed, despite its widespread use and the high esteem with which teaching in the laboratory is held by many teachers, there is little unambiguous evidence to show that, as currently used in many schools, laboratory teaching is any more – or any less – effective in developing conceptual understanding than other, non-laboratory-based, approaches to the teaching of science.

Furthermore, despite claims about its very positive affective value and the large amount of time spent teaching in the laboratory, there remains, unfortunately, a disappointingly low number of students opting to pursue science in the post-compulsory phase of their education. Yet despite this apparent contradiction, many teachers adhere to the view that student motivation towards school science (and many of them would also argue towards science in general) is in some basic way to be seen as being proportional to the amount of laboratory teaching they receive. Such views arise as a result of teachers mistakenly assuming that students' claims to like laboratory teaching are symptomatic of their liking of science as a subject rather than, in many cases, simply reflecting a preference for teaching in the laboratory as opposed to other forms of science teaching (Abrahams 2011). Indeed, the focus on "hands-on" and "minds-off" has tended to mean that much laboratory teaching requires little by way of cerebral engagement. Such a recognition goes some of the way to explaining its relative popularity among students, particularly those who have no interest, or intention, in pursuing science post-compulsion and who would, given the choice, prefer not to be learning science at all.

One positive consequence of the focus on "hands-on" teaching in the laboratory is that it has, through the widespread use of closed recipe tasks, become an extremely effective means of getting students to do, within the often limited time available, things with objects and materials in order to see what the teacher wanted them to see. Indeed, students are frequently able to recollect qualitative procedural details of what they did with a high degree of accuracy, albeit if not with much understanding. Yet despite the effectiveness of much laboratory teaching in terms of getting students to do what the teacher wants with objects and materials, it is much less effective in getting students to learn about ideas, and part of the reason for this lies in the disproportionate amount of whole-class laboratory teaching time devoted to procedural instructions.

Few can doubt that laboratory teaching is, and will remain, a core feature of science teaching, and yet if it is to become as effective in developing conceptual understanding as it currently is in producing phenomena, then change is necessary. That change requires those using it to relinquish their discovery-based approach in favor of a hypothetico-deductive one in which laboratory teaching needs to be designed with the explicit aim of helping to "scaffold" students' efforts to form links between the domain of objects, materials, and phenomena and the domain of ideas.

Cross-References

- ▶ Experiments
- ▶ Inquiry as a Teaching Strategy
- ▶ Laboratory Reports
- ▶ Laboratory Work, Forms of
- ▶ Laboratory Work: Learning and Assessment

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Laboratory Reports

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Keywords

Cognitive and affective domains; Content science-oriented; Inquiry-oriented; Science technology and societal issues

Over the past several decades, we have seen the development, implementation, and evaluation of three generations of high school science curricula: (a) content science-oriented, (b) inquiry-oriented, and (c) problem-oriented (see Lazarowitz 2007). These generational movements are accompanied by changes in science content knowledge, pedagogical content knowledge, textbooks, and modes of teacher instruction. Each of these changes had implications for the nature of laboratory work and the way in which lab work is reported by students.

To illustrate the nature of these changes and their impact on laboratory reports, I describe three generations of biology curricula in Israeli schools.

Content-Oriented Curriculum in Biology

In this first generation, the biology content was presented as a body of knowledge, organized systematically around topics such as invertebrates and vertebrates in zoology, lower and higher plants in botany, and the human body. Each organism was presented in a sequence of morphology, anatomy, physiology, growth, development, and reproduction and introduced with a short description of the cell structure and function. Microbiology, genetics, ecology, and evolution were complimentary subjects. Biology laboratories aimed at learning about organisms and their classification, with the physiology aspects discussed as far as the knowledge in chemistry and physics permitted. Each textbook depicted a sequence from cells to multicellular organisms at different levels of biology organization from the molecular level to the organism. The modes of instruction were expository. Teachers lectured and asked questions, while students listened and sometimes were allowed to ask or answer. Student–student interactions and the process of inquiry rarely occurred.

We can conclude from this description that listening and memorization skills were emphasized rather than learning skills such as seeking knowledge, exchanging ideas, and taking responsibility. The nature of laboratory work was essentially aimed at proving what had already been learned in the classroom. Laboratory reports were used to report results based on a few physiological experiments and microscopic work, drawing cells, and anatomic structures. The reports mainly drew on cognitive levels of knowledge and understanding, with little room for students to record personal thoughts, ask questions, or think critically. Reports were related to past learning, rather than future plans or scientific explorations. Generally, lab reports from this generation of curricula did not include higher cognitive levels such as application, analysis, synthesis, and evaluation (Lazarowitz and Tamir 1994).

Inquiry-Oriented Curriculum in Biology

The late 1960s saw a second generation of high school science curricula based on the concept of inquiry. This approach, rooted in the educational theories of Dewey and Bruner, was developed by Schwab and Brandwein in their landmark book, *The Teaching of Science as Enquiry* (1962). These ideas were later incorporated in Schwab's book, *Biology Teachers' Handbook*, which is considered to be the foundation for the inquiry-oriented curricula, the Biological Sciences Curriculum Study (BSCS).

The content knowledge of the BSCS textbooks was based on the seven levels of biological organization (see, Schwab 1963), emphasizing the teaching of concepts and principles in biology. Teachers were asked to create learning environments, facilitating a process of student/teacher interaction where students had to "search and seek" for knowledge using inquiry skills such as scientists use in their research. In the laboratory, students were required to use skills such as identifying problems, forming hypotheses, planning and experimenting, collecting data, analyzing results, presenting them in tables and graphs, and planning and designing of new experiments. Students were asked to draw conclusions, infer and identify new problems, and read graphs and tables.

The inquiry-oriented curriculum in biology required a new approach to assessing students. Rather than simply repeating facts and information, students had to show in their laboratory reports how these inquiry skills had been applied. Students were expected to demonstrate the use of higher cognitive skills, critical thinking, and problem-solving and affective skills such as responsibility in the learning process. Lab reports were a vehicle for building a body of knowledge on a scientific topic and bridging content from previous laboratory experiences to new laboratory work (Lazarowitz 2007; Lazarowitz and Tamir 1994).

The Problem-Oriented Curriculum in Biology

Since the 1990s, new approaches in science curricula have taken into consideration the heterogeneous nature of students in terms of learning styles, cognitive stages, abilities, choices, preferences, and needs (see Yager and Hofstein 1986). Broadly based on the science, technology, and society (STS) movement, this curriculum generation saw students introduced to science through problem-based thematic material, with units such as Human Health and Science; Ionizing Radiation: Uses and Biological Effects; and Microorganisms.

The laboratory reports from this generation were based on the inquiry demands depicted earlier, with an additional emphasis on societal issues, requiring teachers and students to relate to the affective as well as the cognitive domains. Often students were required to consider both sides of an argument about the use of science and technology in society, such as the use of ionizing radiation in medicine, agriculture, and the food industry vs. its use in war. These and other considerations such as social justice required students to use different kinds of skills in their reports, including problem-solving, argumentation, communication, debate, and the critical use of evidence.

Conclusion

Alongside the three science curriculum generations in the late twentieth century and the early twenty-first century, we have seen several trends in students' laboratory reporting. The first trend is from lower- to higher-level cognitive demands, from reporting and restatement of facts to application, synthesis, and evaluation of scientific ideas. The second trend is towards a better appreciation and explication of the processes of science. Here, students are asked to demonstrate and explain how scientific inquiry proceeds. The third trend – emerging from an understanding of the importance of students' needs and connecting science and technology with society – has tapped into students' affective as well as cognitive skills.

In sum, these trends have resulted in students taking on more responsibility for their own laboratory work, as well as employing the entire range of cognitive, meta-cognitive, affective, and problem-solving skills in reporting their lab experiences.

Cross-References

- ▶ Inquiry as a Teaching Strategy
- ▶ Inquiry, Learning Through
- ▶ Laboratory Work, Forms of
- ▶ Laboratory Work: Learning and Assessment
- ▶ Laboratories, Teaching in
- ▶ Science, Technology and Society (STS)

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Laboratory Work, Forms of

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Keywords

Confirmatory experiment; Demonstrations; Discovery; Experiments; ICT; Inquiry; Practical work

Introduction

There is general agreement that the laboratory provides science students with unique learning experiences. The laboratory utilizes manual and intellectual skills, which are in some measure distinct from those used in non-laboratory work. A comprehensive review of the literature, conducted by Lazarowitz and Tamir (1994), summarized the aims and objectives of laboratory work. These authors suggested that laboratory work be structured under the following main headings: understanding of concepts, acquiring habits and capacities, gaining practical skills (including planning and design of a practical exercise, performance, organization, analysis and interpretation of data, and application to new situations), appreciating the nature of science, and developing attitudes. Whether these aims and objectives are attained, and the form of laboratory work conducted, depends very much on teachers' instructional goals and whether students are provided with genuine opportunities to be involved in laboratory experiences. In addition, the attainment of these objectives is monitored and regulated by the context in which the laboratory exercise is taking place, by the students' characteristics (abilities and motivational patterns), and by the laboratory manual (guide) which very often dictates the type (and form) of activity that will be conducted (e.g., inquiry-type activities as opposed to confirmatory-type experiments, the degree of open-endedness of an activity, and whether the experiment will be conducted by the students individually or in collaborative groups, or presented as a teacher's demonstration). Also, often, the form of laboratory work and the type of activities conducted are based on logistical constraints such as the availability of equipment and materials and the length of the activity.

Forms of Laboratory Work

The two most common organizational structures for the laboratory are teacher demonstrations and experiments conducted cooperatively or individually by the students.

Teacher Demonstrations

The advantage of demonstrations is that the teacher is in control and so able to explain the dynamics and purpose of the experiment in a step-by-step fashion. In addition, the teacher can focus students' attentions toward particular aspects of their observations. When compared to student-led experiments, demonstrations are lower in cost, more economical of time and equipment, less hazardous, generally safer, and more ordered (in terms of directing thinking processes). The way the demonstration is conducted is related to the goals of the experiment(s) and to the type of skills to be developed. For example, if the goal is to develop students' abilities to observe, there may be an advantage to using larger and more accurate demonstration equipment rather than the small-scale equipment available for students' own experimentations.

Student Experimentation

Students' laboratory activities can be classified into four types: confirmatory, inquiry, discovery, and problem-based. Domin (1998) suggested that experiments can be classified according to the type of results obtained from the activity, the approach to the activity (inductive or deductive), who wrote the activity (teacher or students), and who performed the activity. Other researchers (Herron 1971; Pella 1961) suggested categorizing experiments according to their degrees of open-endedness. "Open" in this sense means that the experiment is performed entirely by the student, and "closed" means that it is directed entirely by the teacher. A confirmatory experiment is considered closed when the students perform an experiment that is planned by the teacher. This confirmatory approach is deductive and the results of the activity are known beforehand to both the teacher and the students. By contrast, an inquiry experiment is considered open when the students plan how it will be carried out. This approach is inductive and the results are not known in advance by the students (and in some rare cases, not even by the teacher).

Laboratory Work, Forms of, Table 1 Levels of discovery in the science laboratory

Level of discovery	Problems	Ways and means	Answers
Level 0	Given	Given	Given
Level 1	Given	Given	Open
Level 2	Given	Open	Open
Level 3	Open	Open	Open

Laboratory work may differ in the amounts of responsibility assumed by the learner and the teacher. Several methods have been suggested to analyze (and construct) the types of laboratory activities used in science education, based on assignment of responsibility. Herron (1971), for example, proposed multiple "levels of discovery" which he analyzed according to whether the problems, ways and means of discovery, and answers were "given" or "open" (see Table 1).

Hofstein, Abrahams, and Kipnis (2013) suggested a more elaborate approach to the division of labor in the laboratory between students and their teacher. The traditional confirmatory laboratory and the inquiry laboratory represent two opposite approaches that differ in terms of the role of the student and teacher, the skills that are used and developed during the activity, and the degree of open-endedness of the activity.

The Role of the Students and Teacher in the Laboratory

In the traditional confirmatory laboratory, the teacher plans the experiment, poses the questions during the lesson, and provides detailed procedural instructions regarding the activity. In contrast, the inquiry laboratory is student-centered. In such a laboratory, the students ask the questions, plan the experiment, and control their activities during the laboratory class. The discovery experiment represents another way of organizing the lab. When conducting a discovery experiment, the students perform the experiment according to the teacher's instructions, gather the data, and draw their own conclusions.

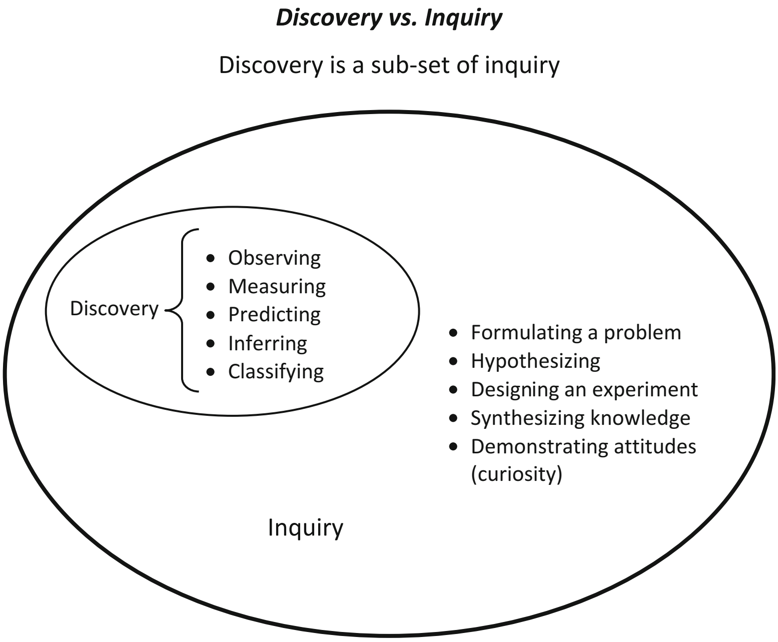
Laboratory Work, Forms of, Table 2 Learning skills involved in confirmatory and open-ended experiments

Learning skills	Confirmatory-type experiment	Open-ended-type, inquiry experiment
Conducting an experiment according to the teacher's instructions	✓	✓
Asking questions		✓
Formulating research questions		✓
Constructing a rational hypothesis		✓
Designing an appropriate inquiry experiment		✓
Conducting the experiment that was planned by the students		✓
Organizing the results	✓	✓
Analyzing the results	✓	✓
Drawing conclusions	✓	✓
Summarizing the experiment's procedure	✓	✓

A laboratory activity can therefore be classified according to the division of responsibility between the students and their teacher. Based on the teacher's aim and/or objectives, teachers can retain or transfer responsibility of some or all of the elements relating to an experiment to the students. Table 2 provides a useful tool for aligning the practical activity to meet the needs and characteristics of each particular class.

Discovery and Inquiry Laboratories

Many science educators use the terms discovery and inquiry interchangeably. Others see discovery as a subset of the inquiry process involving observing, classifying, measuring, predicting, and inferring. Under this definition, inquiry is a broader concept incorporating the additional processes of investigating a problem, hypothesizing, designing an experiment, gathering data, and drawing conclusions. For a schematic presentation of the relationship between discovery and inquiry, see Fig. 1.



Laboratory Work, Forms of, Fig. 1 Skills involved in discovery and inquiry laboratories

The Teacher's Objectives and Behavior in the Classroom Laboratory

The teacher's involvement and behavior during laboratory activities are very important and should not be overlooked. The teacher provides organizers and an environment which affects whether or not the students will reach certain instructional goals and develop the necessary knowledge and skills. The magnitude of the teacher's influence is often related to their overall teaching style. Furthermore, teaching style tends to be consistent regardless of the form of laboratory activity conducted. Deductive-oriented teachers teach practical work authoritatively, while more inductive science teachers use investigative, inquiry-oriented methods of instruction.

Using ICT in the Science Laboratory

Since the early 1980s digital technologies have become increasingly visible in science classrooms and in school science laboratories in particular. There is some evidence that the use of appropriate technologies in school laboratories can enhance learning of important scientific ideas and encourage the development of important high-level learning skills. Inquiry-empowering technologies (Hofstein and Lunetta 2004) may assist students in gathering, organizing, visualizing, interpreting, and reporting data. Some teachers and students also use new technology tools to gather data from multiple trials over longtime intervals (Dori et al. 2013). When teachers and students use these technologies properly to gather and analyze data, students have more time to observe, reflect, and construct conceptual knowledge that underlies their laboratory experiences. Also, using appropriate high-level technology tools can enable students to conduct, interpret, and report more complete, accurate, and interesting investigations. In summary, there is emerging evidence that the integration of ICT tools in the science laboratory is a promising and positive development.

Cross-References

- ▶ Inquiry as a Teaching Strategy
- ▶ Inquiry, Learning Through
- ▶ Laboratories, Teaching in
- ▶ Laboratory Reports
- ▶ Laboratory Work: Learning and Assessment

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Laboratory Work: Learning and Assessment

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Keywords

Argumentation; Inquiry; Investigations; Large-scale assessment; Performance tasks

Laboratory investigations have been a critical component of science education for well over a century. Laboratories were designed to complement more traditional classroom work in order to provide opportunities for students to participate in the cognitive, physical, and social processes of scientific investigation and inquiry. Laboratory experiences were intended to enhance students' understanding of content and provide a learning environment in which students could learn how to use laboratory tools and materials, carry out investigative reasoning, and participate as part of collaborative teams. Thus, laboratories have been designed to be opportunities to learn about both the content and processes of science.

As the nature of scientific investigations has evolved and expanded, so too have laboratory experiences, leading to a recent definition: "Laboratory experiences provide opportunities for students to interact with the material world (or with data drawn from the material world), using the tools, data collection techniques, models, and theories of science" (National Research Council 2006). Advances in technology have broadened the kinds of tools and data that can be used by students in laboratory studies. Such advances no longer limit laboratory experiences to the constraints of the classroom. Students are now able to perform labs using computer simulations, access vast databases of information, or make observations by controlling remote equipment such as automated, high-powered telescopes.

There is a consensus that well-designed laboratory investigations can support student learning if they are based on clear learning goals and are incorporated into the overall science instruction, integrate science content and processes of science, and encourage student reflection and discussion (National Research Council 2006).

Despite these recommendations, research consistently has found that the implementation and impact of laboratory investigations has been quite limited. In many classrooms, students learn how to carry out laboratory procedures but engage in very little reasoning that is central to scientific inquiry. For the most part, students do not pose research questions, design investigations, or build, revise, test, or evaluate scientific models and arguments. Instead, the dominant profile of classroom laboratory investigations is one in which students use tools to make observations and gather data to verify established findings. Frequently, the laboratory experience is episodic and disconnected from ongoing science instruction. Given the general lack of well-designed laboratory investigations, there has been little evident impact of laboratory investigations on student learning. However, there is research that demonstrates positive effects on learning science subject matter when laboratory investigations are well designed and incorporated into the curriculam (National Research Council 2006). In such curricula, laboratory investigations are included along with discussion and lecture and are integral to the learning process. The investigations are used throughout the instructional unit and ask students to develop, test, and verify their ideas regarding the content being taught. Student reflection is stressed throughout the integrated unit, as students are asked to assess their own learning, describe the process they used to construct their ideas, and make sense of their findings.

A number of factors to explain the general disconnect between recommended and observed laboratory practices have been identified. Many teachers do not have sufficient preparation in science and science education to foster inquiry in their students. School organizations and structures can impose constraints that make it difficult for students to pursue research questions that require more time and/or space than the schedule or school setting allows. State science standards and assessments often focus on the learning of specific content at the expense of scientific reasoning and related inquiry processes (National Research Council 2006).

Assessments of laboratory investigations take many forms. In classrooms, teachers assess students as they proceed through the investigation, most often assessing their abilities to carry out procedures, use tools, collect data, and record results. Teachers often conduct a summative assessment of laboratory investigations that includes an evaluation of written and/or oral presentations (Hofstein & Lunetta 2003). In most cases, students are assessed on the extent to which they carry out procedures and are able to verify established science content. However, there is a large set of curriculum and research-based efforts that have designed assessments of investigation skills in which students are expected to develop scientific questions based on observations, arguments, models, and explanations as part of scientific inquiry. In many of these cases, the assessments are a culmination of integrated curricular units in which concepts and inquiry processes are developed simultaneously and students use inquiry processes to develop their understanding of science content.

Two of the most visible instructional programs that assess laboratory investigations are the International Baccalaureate® (IB®) and Advanced Placement® (AP®) programs. Across different science subject areas, IB students are expected to complete an inquiry project and display their understanding of science content through the application of scientific methods, techniques, and explanations. In subjects such as physics, students are also expected to collaborate with students from other schools as a way of emulating a scientific community. The AP science program curricula are currently under revision in order to create a greater balance and coherence among content, inquiry, and reasoning skills. Newly designed assessments in biology ask students to demonstrate evidence of an integrated understanding of conceptual knowledge and scientific practices in particular biology domains.

Laboratory skills have also been the subject of national and international large-scale assessments of student achievement. In general, these assessments have been able to evaluate only a subset of laboratory investigation skills. These assessments typically do not assume that students have studied any particular curriculum and are completed in a relatively short time span. The assessments have varied, however, with regard to the inclusion of performance tasks as well as traditional test item types such as selected-response or short-answer questions.

In the USA, the National Assessment of Educational Progress (NAEP) has used performance tasks to measure science inquiry skills in 4th, 8th, and 12th graders. Earlier versions were conducted with kits, while current versions take advantage of computer simulations (National Center for Education Statistics 2012). Both the earlier and current versions measure process skills of science investigation such as recording and identifying patterns in data, evaluating conclusions based on empirical evidence, and controlling variables to determine the effects of different independent factors. These assessments have been thought of as logical reasoning tasks as all content knowledge is provided to the student within the assessment problem. Students do not need to bring or use any conceptual understanding of particular areas of science in order to successfully solve these problems.

International assessments such as the Programme for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS) also have assessed inquiry in 15-year-olds and fourth and eighth graders, respectively. TIMSS has included a small set of performance tasks as well as short-answer and multiple-choice items that also focus on process skills of science investigation (Gonzales et al. 2008). PISA also contains items aligned with the goals of laboratory learning such as understanding science investigations and interpreting evidence and conclusions. Taken together, these large-scale assessments have focused on processes of science inquiry but have not measured how well students have been able to develop and use investigations to enhance scientific knowledge.

The quality of instruction and assessment of laboratory investigations is related to what students learn from such investigations. The success of laboratory investigations depends on the extent to which they are supported by clear learning goals that emphasize scientific reasoning, content, and processes and are integrated in a strong science curriculum. Despite many promising models and demonstrations, most students (e.g., in the USA) are not yet experiencing laboratory investigations that provide as much attention to the reasoning and content of science as they do its processes.

Cross-References

- ▶ Assessment of Doing Science
- ▶ Inquiry as a Teaching Strategy
- ▶ Inquiry, Assessment of the Ability to
- ▶ Inquiry, Learning Through
- ▶ Laboratories, Teaching in
- ▶ Laboratory Reports
- ▶ Laboratory Work, Forms of
- ▶ National Assessment of Educational Progress (NAEP)
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Language and Learning

- ▶ Dialogic Teaching and Learning
- ▶ Discourse in Science Learning
- ▶ Language and Learning Science

Language and Learning Science

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Keywords

Sociolinguistics

Introduction

Considerations of the roles of language in learning science are not restricted to some particular frameworks or ways of learning. Rather, these considerations encompass unlimited types of social interactions, in both online and offline environments, in formal and informal contexts, involving participants from those so young they are just beginning to learn to talk to those so mature they are the most expert in their field on the planet. Thus, the issue of language and learning science is a topic of investigation not only in science education but also in a wide range of areas including social studies, humanities, and science itself. There is a long and extensive literature focused on language and the learning of science and already many reviews of this work. These reviews have been written from a range of perspectives on the form of language involved (from the specifics of student understanding of particular words used in science to the ways modes of science-related language use such as "argumentation" contribute to science learning) and from a range of perspectives on the forms of learning to which the language is contributing (from language as the tool for transmitting science information to language as an interpretive form of learners' sense making of science and its interactions with society). Given this diversity of perspectives and the number of existing major reviews of research concerned with language and learning science, including whole books, this entry seeks to include a somewhat different approach by attempting to frame these issues in new ways and from perspectives emerging in the twenty-first century. In the first major section (immediately below), there is an outline of the extensive past work, with reference to the more significant extant reviews – this section could be characterized as considering "language and science learning" from within the field of science education. Then the remainder of the entry, the second major section, considers "language and science learning" from quite different perspectives that are currently largely beyond the field of science education.

Language and Science Education: The Range of Science Education Approaches

Publication and citation data (and research, see Fensham 2004, Chap. 15) suggests a rapid increase from around 1990 in the general recognition by science educators of the fundamental importance of the nature of language use in the science classroom. However, research on language and its impacts on how science is taught and learned, and even what science is taught, was taking place in the early 1970s, very early in the development of the discipline of science education.

Understanding of Specific Words

In the early 1970s, a then young science education researcher at Monash University, Paul Gardner, began an extensive research program in which he developed multiple choice items to investigate the levels of student understanding of specific science-related words in Australia, the Philippines, and Papua New Guinea. The words were both "technical" (i.e., in Gardner's terms, physical concepts such as "force" and "mass" and "mole," names of elements and minerals, apparatus, and so on) and "nontechnical" (i.e., again in Gardner's terms, words that are not specific to science but that are frequently used in science contexts with precise science meanings; examples are "random," "predict," "theoretical," "initial"). Later in that decade, Gardner undertook a similarly comprehensive study of student understanding of "logical connectives" (i.e., words or phrases that link between ideas and are central to science arguments and discussions; examples include "therefore," "conversely," "if," "moreover," "further," "thus") and explored understanding when used in both everyday and science contexts. These studies revealed surprising (and disturbing) lack of student understanding of a wide range of words that were at that time being habitually assumed by most science teachers in most parts of the world to be clear to their students. Later studies of understanding of single words have produced similarly disturbing findings, particularly the work in Scotland of Alex Johnstone, work that had substantial impact throughout the UK. Summaries of all this work and its methodologies are given in Wellington and Osborne (2001).

Studies of students' understandings of what Gardner termed "technical words," words such as "energy" or "igneous" or "friction," are fundamentally impossible to differentiate from studies whose stated purpose is to probe students' understandings of science concepts such as "energy" or "igneous" or "friction." This is well illustrated by reports of both probes of student understanding and of student meanings for specific words in the extensive work of the Learning in Science Project in New Zealand (see, e.g., the iconic book by Osborne and Freyberg (1985)).

Broader Science Education Approaches to Investigating Language and Science Learning

The work of the Learning in Science Project, noted just above, is a clear example of the ways in which the growing prominence of constructivist perspectives impacted on almost all areas of scholarship in science learning, including the use and impact of language. As considerations of constructivism became broader in scope via recognition of the sociocultural dimensions of learning, so did perspectives on language and science learning, in particular through the embracing of the ideas of Vygotsky and the centrality of language in all learning by scholars such as the late Phil Scott.

Sutton (1992, 1998) was among the early scholars to seriously argue the need to consider language and its use in science classrooms in terms of students and their interpretations and personal meaning making and the need to reduce the existing strong focus on considering language only as a means of transmitting knowledge. Sutton used the history of science and the ways scientists of earlier times communicated their evolving ideas with each other as a central plank in his arguments. Carlson's (2007) review of research in this area explores a number of new perspectives, including extending Sutton's arguments and use of past communications between scientists into the roles of language in enabling participation in communities of practice.

Research on language and learning more generally also impacted on science education thinking in particular as science educators embraced language ideas from other contexts. Very influential in this was the work of Barnes (e.g., 1976) on the nature and use of language in classrooms, in particular his demonstrations of the powerful positive impact on student learning of personal and conversational interactions between student and teacher and the inhibiting role of rigid and formalized communication structures. These contrasting uses of language he described as "transmissive" and "interpretive" use of language. There are significant links between these arguments of Barnes and the use of the writing of scientists in earlier times by Sutton to make the same fundamental points.

The extensive research on literacy in general has also impacted on language and science education in particular. At one level this has resulted in the dramatic and very rapid increase in concerns with "scientific literacy"; this is addressed elsewhere in the encyclopedia. The more significant of these forms of impacts on language and science learning have come from another source – scholarship in linguistics. As Fensham (2004) has noted "[b]ecause science has developed such a specialised set of conceptual words and its own dialect for internal communication, it is not surprising that, sooner or later, scholars with a general interest in linguistics would turn their attention to the discourses of science and of science classrooms" (p. 203). Of course, being scholars of linguistics, these researchers published in linguistics journals. Lemke, circa 1980, appears to have been one of the first science educators to see the potential of this work and to bring it into science education domains (e.g., Lemke 1990). Lemke has also been a major figure in the ongoing debates about the nature of and interactions between literacy, scientific literacy, and science education and has again used methodologies from the field of linguistics in his work in this area (e.g., Lemke 2004).

More recently there has been an increased emphasis within science education on explorations of the ways the language forms of science per se. These are matters that first attracted the attention of linguistics many decades ago, and can be used to foster school learning of science and about the processes of science. A significant proportion of this work has been focused on argumentation and its use in classrooms to foster learning of and about science. The essential logic of this broad approach is that, just as science considers new ideas and whether or not to accept them via arguments based on evidence, so too should science education be concerned with helping students learn to argue a position from available evidence (and so learn about the concepts relating to the evidence and the ways evidence is gained and used in science). Researchers have explored the consequences for learning of argumentation approaches via verbal and written arguments, from perspectives ranging from cognitive to sociocultural and with ages from primary school to graduate teacher education students (see, e.g., Enduran and Jiménez-Aleixandre 2007).

The entry now moves to possible ways of considering language and learning science that come from beyond the discipline of science education, including outlining developments in linguistics research perspectives that have previously been embraced (e.g., Lemke).

Language and Science Education: Approaches from Beyond Science Education

Language and its role in learning science can be studied by taking into account a wide range of perspectives: determinants that facilitate the processes of decoding new knowledge, the mode of communication (particularly, but not only, since science is transmitted by a range of channels), and the relation between language and science per se. In addition, given the diverse fields of studies devoted to producing and receiving scientific data, any division into domains can also be treated as the categorization of linguistic notions. Moreover, the rapid development of neuroscience and the growing interest in cognitive studies lead to new opportunities for and very different approaches to studying the relation between language and learning science.

Domains of Investigation

The relationships between language and both science education and science per se can be considered by analyzing different linguistic domains of investigation. Language can be perceived, among others, through the prism of sociolinguistics, psycholinguistics, and neurolinguistics – all developments from the earlier linguistics frames that researchers such as Lemke brought to science education. For example, sociolinguists are interested in the way social factors shape the way scientific communication is conducted. On the other hand, psycholinguists pay attention to biological and psychological determinants of learning science. And neurolinguists, different again, focus on the relation between brain functions and neuronal characteristics and their implication for learning and using languages. Moreover, linguistic issues can be studied through the prism of phonetics, morphology, semantics, syntax, or pragmatics. Thus, attention can be paid to morphemes, words, and structures as well as their role in learning. In addition, language in learning science can be approached from the perspective of different areas of research, such as chemistry, physics, biology, and mathematics. Thus, it is possible to focus, for example, on the language and learning of science in the field of physics, by studying how the selection of linguistic tools may determine the understanding of the mathematical formulas that describe the central relationships in physics. These approaches may be connected with similarities and differences in the ways of learning science in various domains and how selected linguistic tools impede or delay the processes of knowledge flows. In addition, it should be noted that learning science is of course not restricted to some types of context. Although it is often associated with formal learning, schooling, or training, in classrooms or lecture halls, acquiring scientific knowledge often takes place in informal settings, such as interactions with colleagues, watching TV, participating in Internet discussions, using some scientific equipment in daily life, etc. (See many entries in this encyclopedia. For example 'Learning science in informal contexts', 'Social networking', 'Technology for informal and out of school learning of science', Television) Researchers investigate the languages used in scientific and science education interactions.

These investigations may explore scientific communication from the perspective of languages used in knowledge learning or the use of specialized languages, genres, or registers in any form of scientific communication. A multilingual approach can be adopted, by investigating the notion of major and minor languages in scientific discourse. For example, some researchers investigate the dominance of English in publishing scientific materials in science in this now de facto global language. The English language is also now increasingly becoming the language of science teaching in countries where English is not the daily language, particularly (but not only) in senior high school levels. The set of complex learning issues associated with learning science in an unfamiliar language – assumptions of learner bilingualism, issues of code switching, etc. – have been the subject of considerable research from within science education in many parts of the globe (see, among many examples, Amin 2009).

Researchers are also interested in the types of texts and channels of communication used in disseminating science itself, as well as increasingly in the teaching and learning of science. For example, the way science is coded determines the possibilities for decoding information by learners. Such studies may focus on online and offline methods of learning science and the linguistic tools used in standard and novel schooling and tutoring.

Translation and Teaching Language for Science: Learning science for many learners also involves working with texts that are translated versions from the source language of scientific texts. Translators have to take into account intercultural differences in coding and encoding science. This encompasses culture-specific preferences as far as knowledge creation and perception are concerned. It involves the methods of encoding (e.g., the level of formality) and the way scientific issues are presented (e.g., the use of passive and active voice). In addition, translating scientific texts involves taking into account the likely level of knowledge among the target audience. In the case of scientific products, such as media programs, scientific entities have to undergo the process of localization to the local market and cultural, technical, and linguistic needs. In addition, learning science is connected with, e.g., teaching foreign languages to scientists and others interested in learning new scientific information (Bielenia-Grajewska 2012). Language for science involves the selection of materials in the target language that meets the needs of learners as far as their level of knowledge, profession, and specialization are concerned.

Neuroscience: The field of neuroscience offers the possibility of providing a detailed and deep analysis of how science is perceived, understood, and used by diversified users. Although learning science is mainly recognized through the prism of education, learning science can also be investigated through other lens, including a range of subdisciplines of neuroscience (Bielenia-Grajewska 2013). For example, in neuromarketing researchers are interested in how purchasers understand scientific data in promotional materials and how the coding of science in advertising determines customer purchasing. Focusing on the linguistic level of neuromarketing, research may concentrate on checking the method of communication and the way it shapes the attitude of customers towards the product and the brand. Noninvasive methods are used in a range of neuroscience areas. For example, functional magnetic resonance imaging (fMRI), a neuroimaging tool using magnetic resonance, is employed in studies to observe brain performance. An individual lies still in a machine for 60–90 min. In the first stage of an experiment that lasts 6–15 min, anatomical scans of the brain are performed. In the later stages, a subject is asked to respond to a stimulus visible on screen. During these activities, it is possible to observe which parts of a brain are active. Later these scans are compared with the anatomical scans performed during the first stage of an experiment. This technique can be used to observe how scientific concepts are perceived by learners and how different forms of linguistic representation determine their scientific cognition.

Methodologies

There is a range of methodologies applied to research on language and learning science and a range of domains and types (as just discussed) to be considered. The focus of investigation can be on issues as varied as culture, communication, or networks in the processes of perceiving and learning and can use qualitative or quantitative approaches.

Text and Talk: Critical discourse analysis (CDA) is an approach used in interdisciplinary research, in which both text and talk in different social situations are observed, by taking into account political, social, and cultural factors shaping the communication. The scope of CDA may vary, depending which aspect of language and learning science one wants to investigate. In a micro approach, one may investigate how the selection of a given word in a text facilitates or hinders the processes of learning science. A meso approach deals with the “middle” dimension of investigating text or talk, taking into account, e.g., content and its role in disseminating scientific knowledge; potential studies include investigation of the structure of a text, its internal division into paragraphs, and the use of punctuation marks to divide information chunks. At a macro level, one may research such concepts as the policy of scientific organization and popularization of scientific products. In addition, CDA allows the study of how literal and figurative tools of linguistic interaction may facilitate the understanding of scientific data. Thus, an analysis of how science is learned can be conducted by use of literal language and symbolic discourse. In addition, the relation between language and learning science can also be studied by paying attention to the nonverbal components of communication. Thus, it is possible to investigate pictorial dimensions of science discourse from micro, meso, and macro perspectives, by, e.g., presenting how the type of fonts (micro approach), the use of pictures or drawings to accompany texts (meso), or the visual dimension of scientific informational campaigns (macro) determine the way science can be perceived by learners. Nonverbal studies can be enriched with investigations of multimodal communication and the semiotic aspects of modern online scientific discourse.

Culture and Communication: Ethnomethodology embraces the study of cultural factors and how these shape the way people communicate. It can facilitate the discussion of how people from different cultural backgrounds encode and decode scientific issues. An example of using the enthomethodological approach is translating scientific data, for example, into a language that is linguistically and culturally distant from the source tongue. Another approach – communication accommodation theory (CAT) – is a cross-disciplinary framework developed by Howard Giles to explain how adjustments in communication are created and how they influence communication flows and distance between discourse participants (e.g., Giles and Soliz 2014). CAT is applied in various disciplines and is used in different contexts to study the ways people change their behavior in communication. As far as learning science is concerned, the approach can be used to show how participants in scientific discourse adjust their linguistic tools to each of the level of interlocutors, type of audience, and topics in focus.

Memetics: A meme is a small element of cultural information. Memes may include, among others, words, concepts, songs, and fashion. Similarly to genes, memes are reduplicated in population (although while genes are reproduced biologically, memes are reproduced culturally). The power of this analogy is reflected in the development of memetics, a theory of an evolutionary model of cultural information transfer. Memetics is visible in the professional life of scientific academics. When a researcher learns an interesting concept himself or herself, he/she repeats the concept among colleagues and students (Dawkins 2006). Learning science can be perceived through the perspective of memes, for example, the introduction of scientific terms into standard languages. When individuals use terminology related to science on an everyday basis, the terms become elements of standard discourse. Memetics can also be used for discussing the translation of scientific texts. Some terms become very popular in the target audience, whereas the unpopular ones do not “infect” new users and die out after some time. Another reason for the rapid duplication of some scientific memes and the quick process of acquiring new terms is the growing role of technology in modern life.

Networks

Network theories are of increasing importance in modern science. The place of language in learning science can also be examined through the prism of grids and lattices. Actor-network theory (ANT) considers both living and nonliving entities, stressing their role in creating and sustaining the performance of a studied entity. For example, in the case of any organization, one may examine the importance of human actors (managers, employees, and customers or students) and nonhuman network participants (computers, faxes, telephones, or furniture) in creating and sustaining discourse. ANT studies have investigated how diversified participants, such as learners, teachers, and scientists, shape the way science is learned. This has been used in work on communities of practice. Since ANT focuses on semiotics as well as the relations between language and learning science, ANT studies also investigate the role of symbolic discourse in coding and decoding knowledge, including the role of metaphors (both verbal and pictorial) in transmitting scientific data.

Other network approaches can be used in investigating the relation between language and learning science. One example is social network analysis (SNA), an approach that views social relationships by analyzing nodes and ties between individuals. Focusing on the linguistic dimension of gaining new knowledge, the perspective of SNA offers the study how social relations shape scientific communication, especially in terms of learning science. One of the applications is to study the transfer of data in homophilous and heterophilous networks. Linguistic homophily can be perceived in terms of selecting similar expressions or communication styles, being often the result of similar background, professional experience, or social factors. On the other hand, heterogeneous social networks rely on using different linguistic codes in communication, represented, e.g., in the adoption of different names for the same notion depending on one's cultural or professional background. The types of linguistic networks have also implications for learning science. For example, homophilous linguistic networks facilitate learning science by relying on a common set of linguistic tools, in principle easily perceived and understood by all participants in knowledge exchange (poor learning outcomes can often be at least partly explained by a science learner not understanding the linguistic tools assumed to be common and understood by the teacher). Although heterogeneous linguistic networks may involve diversified communicative instruments and strategies employed in creating and disseminating science, this diversity can enhance one's interest in science by drawing one's attention to scientific issues presented in different ways.

Considerations of Learner Differences

Types of Learners: Individual characteristics of learners impact on how scientific communication should be adjusted, for example, which linguistic tools seem to be more effective in explaining science to the youngest audience, or how can one best tailor communication to facilitate understanding of new technology among the older generation. The identity of a learner is not fixed, and it is to a large extent context dependant. For example, a learner may be a teacher in some situations, and teachers are very commonly also learners. Thus, the way he/she communicates depends on the role played in a given social interaction.

Gender and Age: Another field of investigation may encompass how gender determines learning science. For example, genderlect styles theory by Deborah Tannen (e.g., Tannen 1996) focuses on differences in the ways men and women communicate. As far as learning science is concerned, researchers are interested how male and female scientists create information and later how the perception and acquisition of science depend on one's gender. In addition, methodologies are selected by taking into account the age of learners (e.g., teaching preschool children, students and learning, mature learners). Thus, the linguistic dimension of learning science is connected with examining how age determines the selection of linguistic repertoire and how the language dimension of science should be tailored to meet the possibilities and expectations of a studied age group.

Learner Identity: The way learners are viewed can be considered through the idea of "identity," a broad concept encompassing such dimensions as individual and professional identity. Individual identity includes issues such as mother tongue and family background, while professional identity includes issues such as professional background, specialized education. The "identity" of a learner can be studied through the perspective of language, thus leading to the concept of "learner linguistic identity." This has particular relevance in the present context by showing how one's identity determines the way science is perceived and acquired by linguistic tools.

Verbal Representations of Science

Lexical Perspective: The lexical dimension of learning science encompasses studies of how the selection of nouns, adjectives, verbs, and pronouns shapes the way individuals perceive and learn scientific concepts. The semantic dimension is characterized by differences in terminology used and the level of specialized terms applied in discourse. Terminology refers to the important aspects of coding and decoding knowledge; in order for scientific terms to be understood, terms should possess one meaning that denotes one scientific aspect.

Grammatical Perspective: A grammatical approach takes into account both morphological and syntactical issues. The link between learning science and morphology concentrates on studying how morphemes, the smallest element of meaning, determine the way science is shaped and understood. For example, the research may focus on the use of prefixes or suffixes in shaping scientific concepts. Syntactical implications for learning science are connected with showing how the principles governing sentences determine the way people perceive and understand science, including the use of tenses and their role in perceiving science. In addition, the use of conditionals shapes the probability of scientific events happening. Another important tool in shaping the attitude is the use of passive voice. Passive voice serves different functions in creating and understanding the language of science, for example, in stressing that the doer of the action is unknown (and thus irrelevant), in highlighting that it is difficult to assign the responsibility for a given action to one person, or perhaps in just focusing on the completed experiment or task rather than the action undertaken.

Nonverbal Representations of Science

Nonverbal representations encompass the use of pictures, drawings, and graphs, often to accompany the verbal form of scientific communication. These are often used to illustrate a given idea or to add additional information that cannot be explained adequately by using the verbal form exclusively. There are also symbolic tools used to disseminate scientific knowledge. An example is a pictorial (visual) metaphor that shapes the way science is perceived. Various linguistic tools are used to disseminate science among specialists and among laymen.

Channels of Communicating Science

Language and learning science can also be studied by taking into account the channels used for communicating science. Thus, language can be studied by observing language in offline and online communication as well as in differences in communication devoted to laymen and to professionals. For example, the language used in online communication is characterized by short forms, abbreviations, and an economical character as far as the selection of complicated linguistic repertoire is concerned. With the laymen-professional dichotomy, differences can be observed both at the semantic and syntactic levels. Complex syntax and compound terminologies often lead to misunderstanding and lack of interest among learners.

Cross-References

- ▶ Argumentation
- ▶ Code-Switching in the Teaching and Learning of Science
- ▶ Communities of Practice
- ▶ Memory and Science Learning
- ▶ Multimodal Representations and Science Learning
- ▶ Neuroscience and Learning

- ▶ Reading and Science Learning
- ▶ Representations in Science
- ▶ Scientific Literacy
- ▶ Socio-Cultural Perspectives on Learning Science
- ▶ Writing and Science Learning

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Language in Teacher Education

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Introduction

Language is central in science teacher education from several points of view: (i) the appropriate use of language strategies in teaching science which need to be modeled by teacher educators and (ii) the importance of language awareness of the preservice teachers themselves as teachers of language and science. Each is considered in detail below.

Language Strategies

At the most basic level, the choice of language strategies is connected to the realization of increasing diversity of linguistic backgrounds of learners in schools. In developed countries this is due to immigration from other countries, and in developing countries, the indigenous population are often learning through a language other than the one they speak at home. According to Yore and Treagust (2006), teachers have been compelled to help students navigate among three different languages – home language, instructional language, and science language. Most learners confront this problem when they move from either their primary language or nonstandard English at home to academic English science language in school. In doing this, preservice teachers need to consider the use of appropriate discourse when they explicitly teach students to talk, read, write, and do science. Once these language abilities are in place, they can be used to learn science content. Where teachers share a common language with their learners, code switching has proved to be a valuable resource for constructing meaning in multilingual classrooms as it offers additional possibilities for richer communication. Code switching is a term used to refer to changing language seamlessly while talking, often in mid-sentence. Although teachers hold differing views about code switching, it can offer an effective way to establish meaning in classrooms where the teacher and the students are able to communicate in the same language and is especially useful when either the learners' or teacher's English vocabulary is limited, making it difficult for them to reformulate ideas in the language of instruction. Code switching can facilitate the establishing of meaning by providing a linguistic and cultural bridge to understanding. Sometimes only a word or two is necessary to provide an English term where the word does not exist in the local language. Preservice teachers need to be alerted to the use of code switching in teaching and its function.

Language Awareness

Two theoretical perspectives have dominated research on language in science. Some researchers examine its use from a cognitivist perspective, while other researchers approach it from a sociolinguistic point of view, enriched by contributions from a situated cognition perspective. Historically, the focus of cognitive psychology has been on words and concepts in the text, while the focus of the situated cognition perspective has been on the discourse employed and its relationship to the learner's social situation. Gee's (2005) use of concepts of life world language and academic social language highlights the distinction between everyday language and the language of science. His emphasis is on the acquisition of academic social language by learners who use the language of learning and teaching as their main language. According to Gee, learners must be able to use academic social language, or they will not access the scientific community of practice. Various characteristics of scientific discourse distinguish it from everyday discourse. For example, a phrase like, "cold temperatures may result in death due to cell destruction by freezing or complete desiccation of plant tissue" can be translated into life world language as "plants will freeze to death in cold weather because their cells will dry out." Such a translation changes the focus such that it has changed from a process (the effect of the low temperatures on plant cells) to the effect on an object (the fate of the plants). Thus, for learners to acquire scientific discourse, texts need to use the language of scientists. Preservice teachers need to become aware that using language involves both accessing discourse and producing discourse, so listening and reading would require accessing discourse, while speaking and writing are the primary means of producing discourse. Teacher education and professional development involve the promotion and facilitation of inquiry science teaching and scientific language teaching among preservice and in-service teachers who have little personal experience in multilingual teaching environments, either as a learner of science or as a teacher of science. Thus, both preservice and in-service education require explicit language instruction. The challenge is to convince science teachers that language is an essential part of doing and teaching science. Activities promoting this view would involve integration of language issues and strategies into methodology courses rather than offering separate language courses. This process requires work on awareness as well as competence.

Cross-References

- ▶ Code-Switching in the Teaching and Learning of Science
- ▶ Curriculum in Teacher Education
- ▶ Language and Learning Science

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Large-Scale Assessment

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Keywords

Large scale assessments; NAEP; PISA; TIMSS

Large-scale assessments are focused on entire education systems and lead to a better understanding of teaching and learning as well as the factors that contribute to constrain or promote achievement. Large-scale assessments provide a feedback to policy makers, researchers, and practitioners who are interested in enhancing educational quality being informed about structures and processes across the various level of education system that limit students' learning acquisition (Greaney and Kellaghan 2008). Their role consists in monitoring trends in achievement over time. The results of a national/international assessment can help identify the magnitude and the influence of various factors which can be handled to provide a better practice in the classroom and to an efficient distribution of resources. The data are usually collected by tests and questionnaires and refer to the students' achievement in the context of their home, classroom, and school environment. The process involves a sample of students of a particular age or grade level who answers multiple-choice and constructed response items.

Programme for International Student Assessment (PISA) is a cyclic internationally standardized assessment, launched by the Organization for Economic Co-operation and Development (OECD) and jointly developed by participating countries (OECD 2012). PISA is designed to collect information through 3 years assessments that allow trend analysis. These surveys are implemented in more than 40 countries and economies being typically administered to 4,500–10,000 students who are 15-year-olds and are enrolled in formal education. PISA aims to provide a new basis for policy dialogue and for collaboration in defining and implementing educational goals through insights into the background factors that influence the development of skills and attitudes necessary for adult life. PISA measures knowledge, skills, and attitudes that cover the domains of reading, mathematics, and science within an internationally agreed common assessment framework based on a dynamic model of lifelong learning. The term "literacy" is used to encapsulate this broader concept of knowledge and skills. PISA's content reflects moving beyond the school-based approach towards the use of knowledge in everyday tasks and challenges emphasizing on the mastery of processes, the understanding of concepts, and the ability to function in various situations. Test items are a mixture of multiple-choice and constructed response items and are organized in groups based on a passage, diagram, or table setting out a real-life situation. Students' outcomes are then associated with students' home background, their approaches to learning, their learning environments, and their familiarity with computers. Two-thirds of students across OECD countries scored between 400 and 600 points, so scales have an average score of 500 and a standard deviation of 100 for each domain. These scale scores represent degrees of proficiency in a particular domain. PISA 2000 defines five levels of proficiency in reading by dividing the literacy scale into five bands. PISA 2003 builds upon this approach by specifying six proficiency levels for the mathematics scale, while PISA 2006 specifies six proficiency levels for the science scale. The PISA provide three main types of outcomes: basic indicators illustrating a baseline profile of the knowledge and skills of 15-year-old students; contextual indicators showing the relationships between such skills and important demographic, social, economic, and educational variables; and indicators on trends revealing changes in outcome levels and their distributions and in relationships between student-level and school-level background variables and outcomes.

Trends in International Mathematics and Science Study (TIMSS) is an ongoing comparative study launched by the International Association for the Evaluation of Educational Achievement, (IEA) which is an independent, international cooperative of more than 60 national educational research institutions and governmental research agencies (Olson et al. 2008). TIMSS is a global endeavor directed by IEA's TIMSS and PIRLS International Study Center at Boston College and provides information about the educational context and achievement of students in a current cycle, while it measures trends from earlier cycles of TIMSS in 1995, 1999, 2003, 2007, etc. TIMSS aims to inform about learning outcomes and about the educational contexts in which students achieve these contributing to a deep understanding of educational processes within individual countries and within a broad international context. TIMSS reflects the latest advances in large-scale comparative assessments of mathematics and science. The assessment framework shows the structure of mathematics and science curricula and provides a tool for comparing and contrasting curricula from different countries. The assessment is administered to representative samples of students from the fourth grade to eighth grade of formal schooling, counting from the first year of primary school (ISCED 1). Each student is administered a single booklet, each one including two blocks of mathematics items and two blocks of science items assembled according to a rotated design and also a questionnaire asking questions about their home and school environments. The math and science teachers of the tested students respond about characteristics of the class, instructional activities, the topics covered during the lessons, and their education, training, and opportunities for professional development. The principals are asked about enrolment and school characteristics, school organization, staffing and resources, as well as the school environment. TIMSS reports on a wide range of topics and subject matters. The 30 different scales (overall achievement, content domains, and cognitive domains for the fourth and eighth grades) are designed to provide reliable measures of student achievement across the trend cycles of the TIMSS assessments. Reporting metric is established by setting the average of the mean scores of the participated countries to 500 and the standard deviation to 100. The achievement levels are established at four cut scores on the mathematics and science scales. TIMSS offer data that can be trusted for important decision making based on comparisons among countries.

National Assessment of Educational Progress (NAEP) is a project of the US Department of Education's National Center for Education Statistics (http://nces.ed.gov). It represents the largest nationally representative and ongoing assessment of America's students in mathematics, reading, science, writing, US history, geography, and the arts and civics for the 4th, 8th, and 12th grades. NAEP examines the relationships between students' performance and various factors. The content to be assessed captures a range of subject-specific knowledge and thinking skills needed by students. NAEP administers tests for different subjects (such as mathematics, science, and reading) in the same classroom, also measuring performance gaps which is done by adding more test questions at the upper and lower ends of the difficulty spectrum. It uses a set of cut scores on the scale that defines the lower boundaries of basic, proficient, and advanced levels. NAEP results are based on representative samples of students; therefore reported average scores and percentages are estimates for the entire population. This assessment provides results on subject-matter achievement, instructional experiences, and school environment for the populations of students and groups in public and private schools. The results are reported only when they are statistically significant and are intended to initiate dialogue among policy makers, educators, and the public.

Cross-References

- ▶ Achievement Levels
- ▶ Assessment Framework
- ▶ Assessment: PISA Science
- ▶ Cut Scores
- ▶ National Assessment of Educational Progress (NAEP)
- ▶ Scale Scores

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Latino Ancestry

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Keywords

Chicana/Chicano; Latina; Hispanic; Mestizo/Mestiza

Useful Controversies

The use of the term Latino/Latina – just like any other identity-related term – is crammed with controversy; and so it should be. The controversies associated with identity terms are in essence the force that urges us to seek better understanding and respect for the labels with which people choose to identify, as well as the community/communities within which they place themselves. This also holds true for the identity labels (and community associations) they choose to reject. Therefore, this entry does not to provide a neat definition that will dispel controversies, nor it provides a one-size-fits-all term. On the contrary, this entry adds to the richness of these useful controversies in hope that the insights shared here will inspire us to continue exploring identity labels and the meanings human beings attach to them and, by doing so, to come to truly recognize the boundaries that define our own sense of self.

Assigned Versus Appropriated Identity Terms

One place to start the discussion is by making a distinction between identity labels assigned by government agencies or others for the purpose of sorting, testing, placing, and categorizing groups of people vs. the labels that individuals choose to call themselves. The term *Latino* (male noun)/*Latina* (female noun) *or Latino/Latina for short* is particularly interesting because it has been appropriated by the peoples of Latin American countries to embody a sense of cultural pride, brotherhood, and sisterhood across the continent. Understandingly, some may disagree with this statement and the apparent oddity of grouping billions of people from the Americas (many of whom speak languages other than Spanish like French, Portuguese, Patois, and numerous indigenous languages and dialects) into such a broad category (Alcoff 2005). Nevertheless, there are common historical and cultural strands that bind Latinos/Latinas together as a distinguishable ethnic group. For example, I was born in Venezuela, and in this country every child undergoes a rigorous indoctrination into Venezuelan history and cultural pride. From elementary and all throughout high school, we are taught about the struggles of indigenous peoples, former slaves, and creoles to end 300 years of Spanish rule over Venezuela and the rest of the continent. There is much shared pride across Latin American countries that united to fight off the Spaniards in long and bloody liberation wars. From an early age, we are taught about the exploits of Simon Bolivar – a Venezuelan Creole born into wealth and who dedicated his life to liberate Venezuela, Colombia, Ecuador, Peru, Panama, and Bolivia (named after him) from Spanish colonialism. One of Bolivar's main ideals was to see a continent united, free from slavery and oppressive foreign rule. In fact, in 1826, Bolivar convened the Congress of Panama and invited all the leaders of the new American States in an effort to strike a treaty of mutual collaboration and defense against foreign powers. The Congress of Panama evolved several years later into what today is the Organization of American States – arguably, the most important inter-American organization in the continent (http://www.oas.org). This is just one of many potential examples of how a spirit of unity is deeply ingrained in the historical DNA of what it means to be a Latina/Latino. This is not to ignore the ongoing conflicts and resentment felt by many Latinas/Latinos as they see their countries' resources ravaged by more powerful continental neighbors, but that is another story for a different book.

To summarize, individuals who call themselves Latinos/Latinas invoke a sense of cultural pride and unity across the continent. This is not the sentiment, however, for many Latinos/Latinas who are designated as *Hispanic* by government agencies. In fact, many of us reject this neocolonial term, and this is the focus of the next section.

Hispanic Versus Latino/Latina

Elsewhere (Rodriguez 2004), it is mentioned that the term Hispanic is offensive to those who prefer to call themselves Latino/Latina as explained above. Generally found basic definitions of Hispanic are "of Spain" or "of Spanish descent." In our view, referring to Latinas/Latinos as Hispanic makes as much sense as calling people from the USA or from India *Britannic* just because they were born in a former colony of Great Britain. It is interesting to note that the USA is the only country in the world to categorize Latinos/Latinas and other individuals with Spanish surnames under the invented category of Hispanic. Indeed, the term Hispanic was appropriated by the US Office of Management and Budget (OMB), and in 1978 it released Directive No. 15 to categorize as Hispanic all individuals who were "of Mexican, Puerto Rican, Cuban, Central or South American or other Spanish culture or origin, regardless of race" (Office of Federal Management and Budget 1997). This directive sought to better monitor and control the increasingly growing population of "Hispanics" after the previously existing quotas for immigration of people from Central and South America and the Caribbean were eliminated in 1965 (Alcoff 2005).

The US Government promptly drew criticism from various scholarly and civil rights organizations since the OMB did not base its classification on existing scientific or anthropological scholarly work, nor did this agency provide clear distinctions between terms (such as, "race" vs. "origin," American Anthropological Association 1997). Another controversial component of Directive No. 15 was the decision to designate Hispanics as the only identifiable "ethnic group." In other words, the OBM required all government agencies to use four race categories, Black, White, Asian or Pacific Islander, and American Indian or Alaskan Native, as well as to use two ethnic categories, Hispanic or Not Hispanic. The rationale for classifying Hispanics as an ethnic category instead of a racial one was because Hispanics can be of any race (Idler 2007). It is very important to point out here that OBM – as well as many similar government agencies around the world – continue to misuse the biological concept of race when referring to human diversity, and what these agencies mean by "race" is the oversimplified and colonial sorting of people according mainly to their skin color. This issue is further developed below, but here it is possible to find common ground with the OBM in the use of the term Hispanic as an ethnic category instead of a racial one. Hispanics (Latinas/Latinos) are a very mixed ethnic group. In fact, a colonial term previously used to refer to Latinos/Latinas was *mestizo/mestiza* (meaning of mixed parents, i.e., European and indigenous parents, or indigenous and Black (slave) parents, or Black and European parents). Thus, a Latino/Latina may appear to be White (European) and a member of the predominant culture in Canada or the USA, yet this individual speaks only Spanish and is ethnically associated with the Latina/Latino culture. In any event, we Latinos/Latinas inherited our dark skin color from our ancestral parents (either the indigenous peoples of the Americas or African slaves or their descendants). Any other shades of skin color in between we owe to our ancestral European parents.

One would have thought that the OBM would have recognized the oddity of continuing to use a colonial system for classifying individuals according to skin color when they were forced to create a new category in order to monitor the population growth of Hispanics. Unfortunately, this was not the case, and the OBM responded to the criticism of its standards for the classification of people by mostly keeping the *status quo*. There were some changes adopted, however, as part of the revision process of Directive No. 15 that was culminated in 1997. Of relevance to this entry, OBM adopted the suggestion to change the term “Hispanic” to “Hispanic or Latino.” Furthermore, “Hispanic or Latino” or “not Hispanic or Latino” remained as the only two ethnic categories. The colonial emphasis of skin-color sorting was softened by changing “Black” to “Black or African American.” The term “White” remained unchanged.

Race Versus Ethnic Group

In the introduction to this entry, it was mentioned that controversies associated with the use of identity terms (either chosen by an individual or assigned by government agencies) are to be expected and in fact useful. However, we could leap forward in the conversation if government agencies were to use scientific research (both biological and anthropological) to provide arguments in support of selected terms to classify our rich human diversity. For instance, it would be useful to finally do away with the misuse of the biological concept of race. In other words, there is no such a thing as distinct races within humans as a species – we all belong to the same race or species – *Homo sapiens*. The minor variability in tones of skin, eye, and hair color and other physical features are not enough to – biologically speaking – differentiate us as distinct races. The misuse of the concept of race – based on superficial characteristics – for sorting, controlling, and discriminating purposes is a colonial leftover in our collective psyche and discourse, which consistently points out to the desperate need for more cross-cultural education in our schools. While racism does exist and persist, this is a social construct; race, on the other hand, is a biological construct based on scientific facts, and there is no excuse for its misuse by government agencies. A more appropriate term to classify (and to celebrate) human diversity in general is “ethnicity.” Ethnicity is defined here as an individual’s choice to associate with a group of people, or ethnic group(s), through common history, cultural practices, and language(s). It is important to stress the importance of an individual’s choice in identifying with an ethnic group because, for example, an individual’s country of origin may be China and that individual may have Asian features, but if that individual grew up in the USA exposed predominantly to Latino and Chinese cultural practices, then that individual may choose to call himself Latino Chinese. In our view, this designation says a lot more about whom that individual is than that person being forced to choose only the category of “Asian” or “Chinese” according to government agencies’ standards. One can easily appreciate the need to follow well-established and agreed-upon categories across agencies and schools for monitoring and research; however, it would be much more useful to document what ethnic group(s) individuals choose and the rationale for their choices. After all, what is the main purpose of a country’s census and of monitoring that country’s changes in population? To make individuals’ fit into convenient preselected (colonial) categories, or to gather meaningful data on individuals to serve their needs? Would it not be more scientifically accurate and informative to gather data on individuals’ own choices for ethnic group(s) association and to explore how trends in these associations change over time, as well as to seek understanding of how new ethnic group associations emerge?

Answering these types of questions will not only help us to better understand and appreciate why some individuals, for example, choose to call themselves Latino/Latina instead of Hispanic, but it will also help us to recognize and celebrate the continuing *mestizaje* (mixing) of our rich cultural and ethnic diversity.

Cross-References

- ▶ Asian Ancestry
- ▶ Black or African Ancestry
- ▶ Cultural Influences on Science Education
- ▶ Cultural Values and Science Education
- ▶ Pacific Island Ancestry

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Learning Cycle

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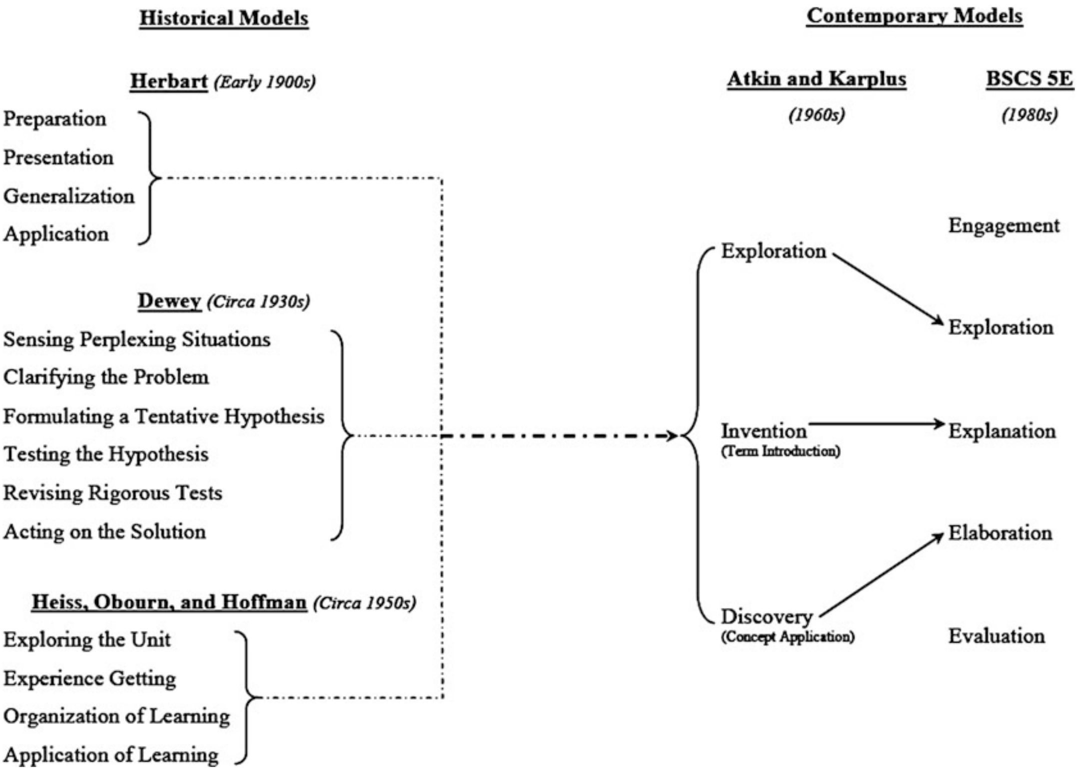
What is a Learning Cycle?

A learning cycle is a term given to describe a particular sequence of instructional emphases designed to promote conceptual understanding. The word "cycle" refers to the repetition of the emphases or phases of the instructional pattern each time a new concept is introduced. An idea related to learning cycle is the instructional model. An instructional model is another lens for considering learning. Rather than thinking in terms of what is happening directly in the learner's mind, an instructional model focuses on the actions taking place in a classroom or a sequence of written curriculum materials to promote a certain set of cognitive activities within the learner's brain to promote the understanding of a key concept.

History

Although the idea of learning cycles and instructional models is not new, their application and use has increased dramatically since the early 1990s. An historical review of this area shows that learning cycles were part of the discussion of educational reform in the United States as early as 1909. Both Johann Herbart and John Dewey wrote extensively about changing instruction by considering the learner's ideas early in the learning process. In 1950, a variation of John Dewey's instructional model emerged in textbooks on science methods for beginning teachers by Heiss, Obourn, and Hoffman. These authors labeled their idea as a "learning cycle" and based it on Dewey's idea of a "complete act of thought," i.e., that reflection must follow observations in order to form a deliberate and complete thought about the phenomenon observed. The work of all these writers strongly influenced the first era of major curriculum reform in science education in the United States in the 1960s. However, the idea of a systematic approach to instruction did not gain widespread acceptance until the development of the elementary project known as the Science Curriculum Improvement Study (SCIS), which incorporated the learning cycle developed by J. Myron Atkin and Robert Karplus. (See Fig. 1 for an overview of the relationship of these various approaches to learning cycles and instructional models).

Karplus began connecting the developmental psychology of Jean Piaget to the design of instructional materials and the teaching of



Learning Cycle, Fig. 1 Origins and development of instructional models

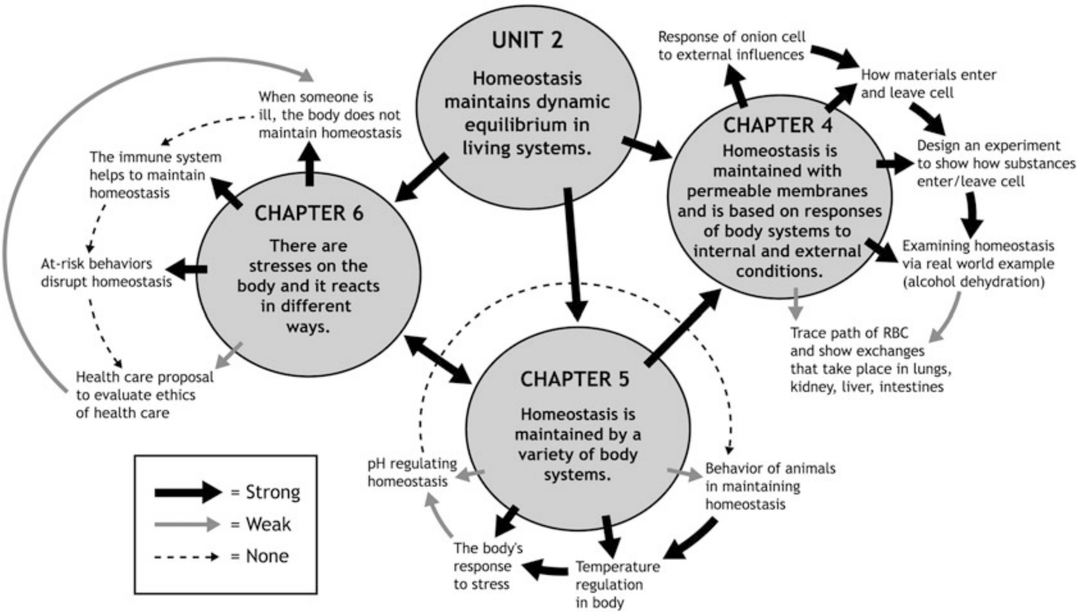
science. Atkin shared Karplus's ideas about teaching science to young children. Eventually, they collaborated on a model of *guided discovery* in instructional materials. Karplus continued refining his ideas and the instructional model as he tested different instructional materials and observed the responses of elementary children. By 1967, Karplus, in his work with Herbert Thier and the rest of the SCIS development team, used these ideas and observations to define the three phases and sequence of the SCIS learning cycle as *exploration*, *invention*, and *discovery*.

During the exploration phase, students have relatively unstructured experiences in which they gather new information about a particular science concept. Then students move to the invention phase in which they invent a formal statement about the concept. Following the exploration, the invention phase allows for the interpretation of newly acquired information through the restructuring of prior concepts. When students are in the discovery phase, they apply their understanding of the new concept to another novel situation. During this phase, the learner continues to develop a more sophisticated level of cognitive organization and attempts to transfer what he or she has learned to new situations.

Initially, the SCIS learning cycle used the terms *exploration*, *invention*, and *discovery* to identify the phases and sequence of the model. In the 1980s, Anton Lawson and others (Lawson 1995) modified the terms used for the learning cycle slightly, to *exploration, term introduction*, and *concept application*. Despite these changes in terminology, however, the key ideas informing what is expected of learners and teachers are essentially the same.

The BSCS 5E Instructional Model

The SCIS learning cycle was the foundation for the 5E Instructional Model that the Biological Sciences Curriculum Study (BSCS) developed,



Learning Cycle, Fig. 2 An example of concepts and science ideas within a curriculum unit

which is probably the most popular version of the learning cycle used in the United States. It is also used in England, Singapore, and regions of China where Teachers Without Borders works. BSCS developed the 5E Instructional Model in the mid-1980s during work supported by a grant from IBM to conduct a design study that would produce specifications for a new science and health program for elementary schools.

In its earliest documentation, the BSCS model had five phases identified by the nouns: *engagement, exploration, explanation, elaboration, and evaluation*. This model was intentionally built from the foundation of the SCIS learning cycle and the earlier models.

Today, the 5Es of the BSCS model are more often known by their verbs: engage, explore, explain, elaborate, and evaluate. This shift came about as the curriculum developers and professional development providers continued to emphasize the role of the student in the learning process, which is driven by this instructional model.

For the language of the BSCS 5E Instructional Model to make sense, it helps to know how BSCS uses terms such as "concept," "topic," and "scientific idea." BSCS refers to a "concept" as complete sentence that describes a relationship among ideas. For example, "homeostasis" is not a concept when stated alone, just a scientific idea without context. For a learning experience, the idea needs to be articulated in the context of other ideas such as this: "Homeostasis is the set of processes that maintain dynamic equilibrium within living systems." Figure 2 is an example of how concepts and ideas are articulated within a curriculum unit and supported by learning experiences. This visual may be useful for understanding how words such as "concept," "topic," and "idea" are used in descriptions of the BSCS 5E Instructional Model.

Table 1 provides a summary of each phase of the BSCS 5Es and a description of the type of classroom activity that supports each phase. It is important to note that the primary function of this instructional model, as with other instructional models based on learning cycles, is to help students develop an understanding of key concepts and ideas such as those in Fig. 1. While BSCS applies the instructional model to the learning of science, the model can be applied to other disciplines to help teachers consider how to structure their instruction to support the learning of key ideas or concepts.

Learning Cycle, Table 1 The BSCS 5E Instructional Model

Essence of phase	The student experience facilitated by teachers and/or curriculum materials will emphasize the following types of mental engagement
Engage	
Mental engagement in a key concept	Students consider a question that directly aligns with the major concept
	Students are encouraged to articulate their current thinking about the scientific idea
	Students are reminded that their ideas may change, grow, expand, or develop
	The classroom culture is developed in a way to support students so they are ready to revisit their ideas once they have examined more evidence
Explore	
Opportunity for inquiry experiences that provide a common experience for all learners in the classroom so later they can contribute to the development of an explanation	Students make predictions or pose a question about a specific phenomenon related to a major scientific concept
	Students collect and use their own data (or data from others) associated with the major scientific concept
	Students are challenged to think critically about the data (e.g., quality and quantity)
	Students begin to make sense of the data
	Students are challenged to consider their current thinking in light of their earlier thinking, which may include posing questions or looking for inconsistencies
Explain	
Students construct scientific explanations	Students have multiple opportunities to connect their ideas and classroom experiences (including those from the previous engage and explore lessons) to make sense of new information
	Students have experiences that offer opportunities for them to examine currently accepted scientific ideas and compare those to their own ideas so that they construct and/or revise their own explanations from evidence
	Students' thinking is challenged by teacher and peers, especially those whose ideas are not aligned with current scientific thinking, including opportunities for students to revisit their preliminary thinking in light of new information provided in the readings or class discussions
Elaborate	
Students have the opportunity to transfer understandings to new contexts. Students may begin to make abstractions or generalizations pertaining to the major concept of the unit	Students consider another scientific question related to the major concept. The question should be an opportunity for students to expand their understanding into deeper or broader contexts
	Students use data associated with the question
	Students think critically about the data (e.g., quality and quantity) with more sophistication because they are using their new information and experiences
	Students use their new knowledge to make sense of the data
	Students expand their understanding by constructing or revising an explanation based on their new experiences and what they have learned previously, especially in the explore and explain lessons
Evaluate	
Both teachers and students have opportunities to assess understanding	Students demonstrate their current understandings and abilities associated with the major concept of the unit
	Include components for self, peer, and teacher evaluation

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Effectiveness

The research on learning cycles, including the BSCS 5E Instructional Model, does not tell a single story (Bybee et al. 2006). One general finding across 30 years of research in elementary through college settings is that students who learn using instructional materials based on a learning cycle learn about the same with respect to traditional academic content knowledge as their counterparts who learn the same content via more traditional instruction dominated by lectures in which information is transmitted and lab experiences in which students follow very specific directions to verify an expected or known outcome. While the research results regarding the effectiveness of learning cycle and instructional model approaches in general are mixed, there are also numerous studies that show better academic gains for students who were taught using a learning cycle approach and no studies where students in learning cycle settings do worse than those in traditional settings. What is particularly significant is that students learning from a learning cycle approach typically show better results than students learning from more traditional instruction as regards the persistence of learning, as measured by delayed posttests of students' understanding of science concepts. This means that students who learned via a learning cycle approach did not just learn the key words or labels of science, but understood the relationships among topics and ideas and that understanding was persistent. Similarly, the research shows more positive attitudes and better understanding of the nature of science and scientific inquiry among students in classes where a learning cycle approach is used compared with those results among students in classes where a traditional approach is used (Wilson et al. 2010).

Cross-References

- ▶ Dewey and the Learning of Science
- ▶ Piagetian Theory

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Learning Demand

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Definition and Origins

Learning demand is a tool to characterize the nature of differences between the conceptual scientific content to be taught in a sequence of science lessons and the likely knowledge of students of a given age and prior instructional experience at the start of teaching.

Since Piaget's pioneering work, it has been known that people (and particularly children and adolescents) explain natural phenomena in predictable ways that are often at odds with accepted scientific explanations. Between the 1970s and 1990s, a significant amount of research was conducted to document, characterize, and theorize young people's explanations of natural phenomena explained by concepts in school science curricula. This work also showed the ways in which young people's characteristic ways of thinking influenced the outcomes of school science teaching. By the mid-1990s emphasis in the research community had moved away from the documentation of young people's explanations as an end in itself towards the design of science teaching. By the early part of the new millennium, an increasing number of studies were appearing which explicitly addressed the design and evaluation of science teaching sequences and learning environments. For a fuller account of the development of the literature on the design of teaching for conceptual understanding in science, see the entry on "▶ Evidence-Informed Practice in Science Education."

John Leach and Phil Scott (University of Leeds, UK) developed the notion of learning demand in 1995, as set out in Leach and Scott (2002). The initial stimulus for the work was comparing characterizations of the explanations of young people aged 5–16 about selected ecological concepts with the explanations demanded by the school curriculum. The focus quickly moved towards developing a tool to inform their work on designing and evaluating teaching sequences about specific scientific content at a fine-grain size. A social constructivist perspective on science learning informed their work. Following Bakhtin, school science was assumed to be a social language in itself. Science learners were assumed to have an "everyday" social language through which the phenomena and events of science lessons were understood. This "everyday" social language is often contradictory to the social language of school science. Furthermore, as students are exposed to the social language of school science, their "everyday" social language develops – though not necessarily into the social language of school science that is the target of the curriculum.

Learning demand compares the social language intended to be developed by students at the end of a given teaching sequence and the social language that the students characteristically use at the beginning of instruction. The purpose of identifying learning demands is to bring into sharper focus the intellectual challenges facing learners as they address a particular aspect of school science. Learning demands contrast the conceptual tools (including the ontology on which the conceptual tools are based) and the epistemological underpinnings of the social languages of school science, with the social language of students prior to instruction.

The identification of learning demands is illustrated through the example of introducing English students (aged 11–13) to a model of energy transfer via an electric current, where current is conserved and energy is transferred in resistive parts of the circuit. The social language of school science was identified from official curriculum documents as being built upon conceptualizations such as:

- Current as a flow of charge
- Current as the means of energy transfer
- Current as being conserved
- The supply of energy as originating in the electrical cell
- Energy being transferred in resistive elements of the circuit

These conceptualizations rest on ontological assumptions about the nature of current, charge, and energy. Studies of the research literature on young peoples' characteristic explanations, however, suggest that their social language is likely to include conceptualizations and ontology which contrast with the social language of school science, such as:

- Batteries run out
- Electricity makes things work
- Current, electricity, volts, and power are the same kind of thing
- Electricity/electric current flows

In addition, the scientific social language is based upon epistemological assumptions such as the need for one explanatory model to explain all electric circuits, whereas the research literature suggests that 11- to 13-year-old students may not assume that this is the case.

Use of Learning Demand as a Design Tool

In 2009, Ruthven and colleagues defined the purpose of design tools as coordinating and contextualizing theoretical insights on the epistemological and cognitive dimensions of a knowledge domain for the particular purposes of designing teaching sequences and studying their operation at a fine-grain size. Learning demand is one design tool used to illustrate the argument; others include a didactical situation and didactical variables (Brousseau), knowledge distance and modeling relations (Tiberghien and colleagues), and communicative approach (Eduardo Mortimer and Phil Scott). Design tools are defined as being theoretically embedded in intermediate theoretical frameworks (such as, in the case of learning demand, social constructivism) and grand theories (such as, in the case of learning demand, sociocultural accounts of meaning-making as proposed by Vygotsky, Bakhtin, and Wertsch).

Examples of Use

The concept of learning demand has been used by researchers and doctoral students at the University of Leeds over a number of years in the design and evaluation of teaching sequences in various conceptual areas. In 2006 Leach, Scott, and colleagues reported on three case studies where an analysis of learning demands was drawn upon explicitly to inform the design, implementation, and evaluation of three teaching sequences for lower secondary school students in England. For two of the three case studies, there is clear evidence that after teaching students were better able to “speak the social language of school science” than comparable peers who had followed their school’s usual teaching approach.

Ph.D. studies which have drawn upon the notion of learning demand in the design and evaluation of teaching have been carried out in the following conceptual areas and countries:

Chemical kinetics (Turkey; Uganda)
Differentiating physical and chemical change by the use of a simple particle model of matter (Saudi Arabia)
Plant nutrition (Saudi Arabia)
Electrochemistry (Malaysia)
Energy (Cyprus)

In each case, there is evidence that students following the designed teaching sequence perform significantly better in post-teaching tests than comparable peers who follow the school’s usual teaching approach.

Cross-References

- ▶ Action and Science Learning
- ▶ Didactical Contract and the Teaching and Learning of Science
- ▶ Heterogeneity of Thinking and Speaking

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Leach J, Scott P (2002) Designing and evaluating science teaching sequences: an approach drawing upon the concept of learning demand and a social constructivist perspective on learning. Stud Sci Educ 38:115–142. This paper describes learning demand and its relationship to underpinning perspectives on learning science in formal settings

Millar R, Leach J, Osborne J, Ratcliffe M (2006) Improving subject teaching: lessons from research in science education. Routledge Falmer, London. The book includes detailed accounts of the design, implementation and evaluation of three case studies of lower secondary school teaching (plant nutrition, introduction of a simple model of the structure of matter, electricity) based upon the use of learning demand as a design tool

Ruthven K, Laborde C, Leach J, Tiberghien A (2009) Design tools in didactical research: instrumenting the epistemological and cognitive aspects of the design of teaching sequences. Educ Res 38(5):329–342. This paper describes how grand theories, intermediate theoretical frameworks, and design tools have been drawn upon in selected traditions of theoretically-informed design of science teaching. Learning demand is one design tool described

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Learning Environment Instruments

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Keywords

Classroom environment; Student perceptions

Research and evaluation within the context of science education traditionally relies on assessment of academic achievement and other valued learning outcomes. However, these educational measures do not give a complete view of students’ educational experience. In particular, students’ perceptions of their school experience are also significant. Researchers have made considerable progress over the past 40 years in both conceptualizing and assessing determinants of the psychosocial learning environment in classrooms and schools (see Fraser 2012). This has in turn led to development and validation of a variety of robust instruments that measure the learning environment in a range of contexts. Early learning environment instruments include the Learning Environment Inventory (LEI) developed by Herbert Walberg (1979) and the Classroom Environment Scale developed by Rudolf Moos (1979).

Using students’ perceptions to describe educational contexts is at the core of what learning environments research does. However, other approaches to studying educational environments can involve naturalistic inquiry, ethnography, case study, or interpretive methods. Defining classroom environment in terms of the shared perceptions of students has the advantage of characterizing the setting through the eyes of the participants themselves and for capturing data which a researcher might otherwise miss or consider unimportant. Students can be said to possess a unique vantage point for making evaluative comments about classrooms as they have typically experienced different learning environments and spend enough time in a class to form accurate impressions. What follows is a sample of instruments that have been developed and validated for specific learning contexts.

Sample Instruments

This section describes a small subset of instruments that study unique learning environment perspectives in order to give the reader a flavor of the diversity of studies possible in this growing field of inquiry.

Questionnaire on Teacher Interaction (QTI)

The QTI was developed from research begun in the Netherlands focusing on the nature and quality of interpersonal relationships between teachers and students. Drawing upon a theoretical model of proximity (cooperation-opposition) and influence (dominance-submission), the instrument assesses student perceptions of eight aspects of teacher behavior using items with a five-point response scale ranging from never to always. Typical items are as follows: “She/he gives us a lot of free time” (student responsibility and freedom) and “She/he gets angry” (admonishing behavior).

Science Laboratory Environment Inventory (SLEI)

Because of the uniqueness of laboratory settings in science, an instrument suited to assessing the environment of science laboratory classes was developed. The SLEI has five scales (each with seven items) and a five-point Likert-type response scale. Typical items are “I use the theory from my regular science class sessions during laboratory activities” (integration) and “We know the results that we are supposed to get before we commence a laboratory activity” (open-endedness). The SLEI was initially field tested and validated with a sample of over 5,447 students in 269 classes in six different countries (the USA, Canada, England, Israel, Australia, and Nigeria), then later cross-validated with classes in Singapore and Australia.

Constructivist Learning Environment Survey (CLES)

In the constructivist view, meaningful learning is a cognitive process in which individuals make sense of the world in relation to the knowledge they have previously constructed, and so, the sense-making process involves active negotiation and consensus building. The CLES was developed to assist researchers and teachers to assess the degree to which a classroom learning environment is consistent with this constructivist epistemology and to assist teachers to reflect on their assumptions about knowledge and to reshape their teaching practice.

What Is Happening in This Class (WIHIC) Questionnaire

The WIHIC questionnaire added some continuity to the field of learning environment research by combining modified versions of the most salient scales from a wide range of preexisting questionnaires with additional scales added which addressed some emerging and contemporary educational concerns (e.g., equity). The WIHIC has a class form (which assesses a student’s perceptions of the class as a whole) and personal form (which assesses a student’s personal perceptions of his/her role in a classroom). The final form of the WIHIC contains seven (eight-item) scales and has been used extensively in its original or modified form in studies worldwide (Fraser 2012).

Place-Based Learning and Constructivist Environment Survey (PLACES)

The Place-Based and Constructivist Environment Survey (PLACES) is an example of a recent questionnaire. It was created in order to assist in the description of environmental education settings and was developed in two stages. First, a pilot study was conducted by adapting scales from established inventories such as the WIHIC and SLEI and others such as the Science Outdoor Learning Environment Instrument (SOLEI). A total of eight scales were referenced. After this exploratory work, a more robust instrument for use in place-based environmental education settings was developed, including such unique factors such as environmental interaction or community involvement.

Conclusion

The brief descriptions provided here for selected learning environments give only a flavor of the breadth of learning environment instruments that have been created for research across a wide variety of settings. Although the study of learning environments has its roots in science education, its conceptual framework provides for an important and often overlooked perspective on the educational experience. As such, new instruments are also available for studies in contexts such as ICT-rich environments and sustainability related education practices.

Cross-References

- ► Classroom Learning Environments
- ► Classroom Organization

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Learning in Play-Based Environments

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Introduction

Understandings about learning in play-based early years' education contexts (for children aged from 6 weeks to 8 years) have become increasingly diverse and complex in recent years. Many early years' learning and curriculum frameworks developed in countries around the world over the last decade or so reflect a shift away from *developmentally appropriate practice* that closely linked children's learning capacities to their developmental "stage" and advocated child-centered approaches that primarily involved teachers responding to children's self-initiated interests and self-directed play. Especially in predominantly European-heritage countries, play is still considered essential to children's learning. However, conceptualizations of play, and views about the extent to which, and ways in which, teachers should engage in children's play vary widely. The following discussion identifies some new understandings about learning in play-based contexts and flags some associated debates.

Very Young Children Actively Engage in Learning in Play-Based Contexts

A growing body of contemporary research in naturalistic contexts shows that babies and toddlers (aged up to 2 years) actively participate in early years' settings in much more sophisticated ways than was often previously realized. Much of this research (e.g., Berthelsen et al. 2009) illustrates the babies' and toddlers' interest in developing relationships with peers and adults and the wide range of strategies they use to do so. Their learning is relational in that it occurs within relationships. Very young children, like their older counterparts, learn by actively participating in their social and cultural worlds (Berthelsen et al. 2009). These worlds provide many opportunities for babies and toddlers, in their day-to-day lives, to encounter, engage with, and learn about aspects of literacy, mathematics, and science and about other social, cultural, and physical phenomena that typically fall within the scope of curricula.

Curriculum and learning frameworks are increasingly inclusive of babies and toddlers. They raise a range of issues about very young children's learning (as opposed to the more traditional focus on their development) in early years' settings that require further investigation. Research in naturalistic settings also highlights babies' and toddlers' capacities to take the initiative, to engage purposefully in learning, and to sustain intense concentration for long periods. Increasing recognition of the sophistication of babies' and toddlers' learning has generated debate about terminology, such as the term "infant education and care." The importance of positive and caring relationships for babies' and toddlers' learning is not disputed. Rather, debate focuses on whether the term education adequately reflects and encompasses caring relationships. Conversely, does the stand-alone use of the term "care" do justice to the complexity of babies' and toddlers' learning and sufficiently convey educators' responsibilities for fostering that learning in play-based contexts?

The Importance of Teacher Involvement in Play-Based Learning

Powerful evidence of the importance of active teacher involvement in children's play-based learning has been provided by the influential UK study, the *Effective Provision of Preschool Education* (EPPE) (1997–2003), and later extended to the *Effective Pre-School and Primary Education 3–11* (EPPE 3–11) Project (1997–2008) (http://eppe.ioe.ac.uk/) and the related study *Researching Effective Pedagogy in the Early Years* (1997–2003) (https://www.education.gov.uk/publications/eOrderingDownload/RR356.pdf). These studies generated the term "sustained shared thinking," which refers to at least two people working together in ways that require them to draw on their intellectual resources – for example, to solve problems, clarify concepts, evaluate activities, and extend narratives. Each person engages with the thinking of the other participants to co-construct new understandings. Crucially, all participants are involved in extending thinking and developing new understandings (Siraj-Blatchford 2009). These landmark studies have prompted many subsequent rich accounts of sustained shared thinking in early years' settings that illustrate joint involvement of children and adults and children and their peers in child- and adult-initiated play-based learning.

Drawing on the work of Russian psychologist Lev Vygotsky, Fleer (2010) provides another, complementary, way of theorizing the pedagogical role of play in concept formation. She proposes the term conceptual play to refer to the play that assists children to develop scientific or other academic concepts. Fleer suggests that the teacher's role is to analyze children's play and to discern key moments in the development of their understandings. The teacher can then seize the opportunity to frame the play activity conceptually in ways that encourage children to think about the concept.

Fleer (2010) made the point that simply providing opportunities for children to play with a range of interesting materials and objects is unlikely to lead to scientific learning. In illustration, she described a group of preschool children playing with colored water and plastic tubes, funnels, containers, and bottles with pump dispensers. The teacher anticipated that playing with these materials and objects would enable the children to develop scientific understandings (e.g., about the density of substances and how they mix). The children, however, developed a play script that involved making medicine to treat a "Humpty Dumpty" soft toy that repeatedly fell from a wall. While they used materials and objects provided by the teacher, their play did not lead to conceptual learning. The teacher did not participate in the children's play and was not concerned about what some would see as a lost opportunity for learning. Rather, she valued their imaginative play. Fleer speculates about what learning may have happened had the teacher intervened in the children's play script. For example, the teacher could have commented that as Humpty Dumpty kept falling off the wall, the medicine was clearly not working and suggested that the children experiment by mixing substances to create a range of different medicines. Fleer's vignette provides a glimpse into the ongoing debates about different types of play, their respective contributions to children's learning, and the degree to which is it appropriate that choices about play are negotiated between children and adults (Wood 2010).

Play-Based Learning Can Exclude Some Children

A different set of concerns and debates about learning in play-based contexts focuses on claims that play can easily be romanticized or seen as unequivocally beneficial. But as Wood (2010) and Grieshaber and McArdle (2010) argue, along with many other critical and post developmentalist theorists, play can both mask and highlight complex power relations, for example, in children's interactions that lead to some children being routinely excluded on the basis of gender, ethnicity, social class, sexuality, ability/disability, or any other kind of difference. Play-based settings can also inadvertently exclude for children from cultures where play is not particularly valued as a vehicle for learning. Uncritical acceptance of long established, unquestioned assumptions about play can therefore have profound implications for the efficacy of play-based learning contexts for different children. Differential access to participation in play, in turn, can have profound social justice implications.

On the other hand, play dynamics can provide a valuable context for involving children in discussions of diversity, difference, inclusion, exclusion, and social justice. In doing so, they can pave the way for building more inclusive play-based learning environments and creating more equitable learning opportunities.

Conclusion

In summary, learning in play-based contexts raises complex issues that require ongoing consideration. Play-based environments are not a panacea. They present many potential pitfalls but if these are reflexively, creatively, and respectfully negotiated, they can be rich with possibilities for learning.

Cross-References

- ▶ Curriculum in Play-Based Contexts
- ▶ Early Childhood Science Teacher Education

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Learning of Science – A Socio-Cultural Perspective

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Keywords

Cognitive; Cross-cultural; Discourse; Diversity; Identity; Learning; Place-based; Sociopolitical

The study of science learning from sociocultural perspectives has largely focused on the question of how students from culturally, socioeconomically, and linguistically diverse backgrounds can all be engaged in science learning in ways that allow students to make personal connections between their own lived experiences and core science content and practices. Researchers have addressed this question using a range of theoretical perspectives, including a cognitively based perspective, a cross-cultural perspective, a sociopolitical perspective, and other emergent perspectives. Proponents of these varied perspectives share the belief that connecting students' cultural and linguistic experiences to the practices of science is central to students' science learning; however, the specific approaches proposed to best achieve this goal differ.

Proponents of a cognitively based perspective have done research grounded in cognitive science that often focuses on students' scientific reasoning and classroom argumentation (e.g., Warren et al. 2001). These scholars have generally argued that students' ways of knowing and talking can be viewed as continuous with scientific practices and that if teachers identify and incorporate students' cultural and linguistic experiences as intellectual resources for science learning, then students will come to view themselves as successful science learners and members of a science learning community.

Proponents of a cross-cultural perspective have done research grounded in multicultural literature that often focuses on students' cultural norms, beliefs, and practices. These scholars have generally argued that students who lack sufficient background in the scientific "culture of power" (e.g., Western modern science) may possess cultural beliefs and practices that are discontinuous in some ways with scientific practices and school science norms (e.g., Lee et al. 2007). This research often proposes that teachers make the norms of school science explicit and help students learn to cross cultural borders between home and school while aiding students in maintaining their cultural and linguistic identities.

Proponents of a sociopolitical perspective have done research grounded in critical theory that often focuses on power relations. These scholars have generally argued that science itself can and should be reconceptualized to better incorporate the worldviews of people from marginalized groups (e.g., Calabrese Barton 2001). Findings from this work include the value of science learning that builds trusting relationships between teachers and students so that students come to see their teachers as allies in a struggle against oppression rather than as part of an oppressive system. In this way, more students come to engage in science in socially transformative ways.

Other emergent sociocultural perspectives on science learning include a focus on science learner identities (Carlone and Johnson 2007), the role of third (or hybrid) spaces in science learning (Calabrese Barton et al. 2008), and place-based approaches to science learning (Buxton 2010).

Cross-References

- ▶ Discourse in Science Learning
- ▶ Identity
- ▶ Socio-Cultural Perspectives on Learning Science

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Learning Progressions

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Keywords

Assessment; Conceptual change; Curriculum; Learning trajectories

What Are Learning Progressions?

Children come to school with powerful ways of making sense of the world around them. Their ways of reasoning work in familiar situations; however, this naïve reasoning is often not scientifically accurate and may not hold up when students encounter phenomena that their reasoning schemes cannot explain. A central goal of K-12 science education throughout the world is to support students in moving from their initial ways of reasoning about the world to more coherent scientific reasoning that fuses science practices, crosscutting concepts, and disciplinary core ideas that hold broad explanatory power (e.g., National Research Council 2011). However, even after over a decade of formal science education, many students leave high school still using their initial sense-making schemes to explain the natural world.

Developmental psychology, sociocultural theory, science education, and other domains provide rich insights into how students learn and why they may not develop coherent scientific explanations about the natural world. However, until recently it was rare for these domains to inform one another. In addition, again until recently, these research studies have largely not influenced science education policy, commercial curricula, or large-scale assessments. This may be in part because many research studies are limited in duration and scope. Studies in science education often focus on student learning in a single unit with no connections across years or disciplinary core ideas; many developmental psychology studies are done in laboratory contexts without a classroom instructional component, thus making the findings difficult to apply to school settings; and sociocultural studies often have limited sample sizes and are focused on specific groups of students, making generalization difficult. Thus, there is a need for frameworks that can merge the findings from multiple domains to build a more powerful and coherent understanding of how students learn in the long term. Learning progressions provide this structure.

Learning progressions, in their current form, have developed rapidly over the last 15 years (primarily through research and development in the USA). Learning progressions bring together research findings from these different domains (e.g., developmental psychology, science education, psychometrics) and fuse them to build a more coherent structure for understanding how students learn. Learning progressions have been defined as, "descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time (e.g., 6–8 years). They are crucially dependent on instructional practices if they are to occur" (NRC 2007, p. 214).

Learning progressions do not represent just a scope and sequence of topics to be learned or facts to be added to students' repertoires. Rather, learning progressions represent a hypothetical framework that (a) links the ideas that students bring to school (at lower levels of a learning progression) with the socio-scientific ideas that students need from schooling to be knowledgeable citizens (at the upper level of a learning progression) and (b) illustrates pathways and of increasing sophistication in student reasoning about disciplinary core ideas (the middle levels of the learning progression).

Design and Essential Features of Learning Progressions

Through incorporating both a top-down (the structure of the discipline) and bottom-up (what we know about how students learn) design process, learning progressions combine ideas from multiple disciplines to provide a coherent framework for describing the development of students' knowledge and practice (Alonzo and Gotwals 2012). Learning progressions prioritize disciplinary core ideas and practices that are generative and worth focusing on for extended periods of time. As part of the top-down design of learning progressions, scientists and science educators identify disciplinary core ideas, crosscutting concepts, and science practices based on the knowledge needed for understanding socio-scientific issues and promoting scientific literacy. What separates learning progressions from other frameworks is that they also prioritize how students learn these disciplinary core ideas, crosscutting concepts, and science practices. A logical decomposition of the core ideas by scientists may not necessarily represent the paths that students take as they learn the content. Thus, learning progressions also include a bottom-up process based on empirical studies of students' sense-making processes and the nature of students' thinking as they develop more sophisticated understandings.

While learning progressions may differ on some aspects, most current research on learning progressions use similar frameworks and essential components to describe learning progressions. Corcoran et al. (2009) identify five essential components of learning progressions: (1) learning targets or end points, (2) progress variables, (3) levels of achievement, (4) learning performances, and (5) assessments.

Learning targets or end points, also known as upper anchors, are based on knowledge needed to participate in society in a scientifically literate way. These learning targets result from a deliberative process that includes (a) an understanding of the core disciplinary ideas, (b) social aspirations for citizens of a just and technologically sophisticated society, and (c) science education research that produces empirical evidence about the intellectual resources that students bring and the ways that they respond to appropriate instruction.

Progress variables identify the aspects of disciplinary core ideas, crosscutting patterns, and science practices that are present in some form at all levels of achievement, so that their development can be traced across levels. The development of progress variables is an iterative process (i.e., employing both a top-down and bottom-up process); they are derived partly from theories about how knowledge and practice are organized and partly from empirical research on student reasoning.

Levels of achievement are patterns in learners' disciplinary core ideas, crosscutting concepts, and science practices that extend across progress variables. This is a key part of the learning progression hypothesis – students' performances for different progress variables will be aligned in predictable ways. As with progress variables, the development of levels of achievement is iterative; they are based partly on research about what constitutes higher and lower levels of performance and partly on data about students' actual performances. It is mainly in the levels of achievement where the bottom-up approach to learning progressions is important because learning progressions do not impose normative models of understanding science on student learning. Using the bottom-up approach helps define the middle or intermediate levels of the learning progression.

Research shows that students' intuitive ideas about the natural world can sometimes be barriers to more sophisticated understandings. However, learning progressions also search for some of the intermediate ideas students have that may be productive stepping-stones on the way to scientific understanding. These intermediate stepping-stones may not resemble the scientifically correct idea in that they are either a gross simplification (e.g., genetic information specifies the structure of proteins) or even scientifically inaccurate (e.g., equating weight with mass), but may be conceptually productive steps in the process of moving from naïve ideas to more sophisticated scientific reasoning (Duncan and Rivet 2013). Students' naïve ideas, then, are not just seen as misconceptions that need to be replaced, but are recognized as students' ways of making sense of the world around them and bases for further learning. Thus, these ideas can be used as leverage points to engage students with the scientific ideas and to help students restructure and reorganize their intuitive ideas into scientific theories.

Learning performances are the specific practices characteristic of students who are at a particular level of achievement and reasoning about a particular progress variable. Describing specific learning performances is at the core of the learning progressions hypothesis: the learning performances should provide specific predictions about student reasoning and student learning that can be tested empirically. Thus, it is through learning performances that we can link the learning progression framework to empirical data from assessments and teaching experiments, enabling us to test the learning progression hypothesis.

Assessments provide tasks that allow students to reveal their reasoning about the progress variables in the learning progression. Initially, researchers attempt to match student responses to the framework and use these responses to provide information to iteratively refine the levels of achievement (or even the whole progress variable) defined in the learning progression. Once the learning progression has validity evidence underlying it, student responses can be used to place students at particular achievement levels, which can provide stakeholders with information about these students' understandings.

While learning progressions often lay out levels of increasing sophistication of students' abilities to use disciplinary core ideas and scientific practices, this does not imply that students' learning necessarily follows a linear path. Rather learning progression levels represent patterns in students' ideas as they become more sophisticated. By providing this framework that lays out students' ideas that range from naïve to more sophisticated, learning progressions illustrate the range of ideas students may have around disciplinary core ideas, crosscutting concepts, and science practices. These frameworks, then, can guide the development of standards, assessment, instruction, and professional development.

The Role of Instruction

Researchers agree that students will not move up a learning progression without instruction and that traditional instruction may not allow students to reach the desired upper-level understandings (learning targets) for meaningful engagement with socio-scientific ideas and practices. However, the role of instruction in defining a learning progression varies among research projects. In some projects, learning progressions are designed to illustrate what is possible for students to achieve with specific instructional experiences. In these learning progressions, researchers document how experiences allow students to engage with the disciplinary core ideas and crosscutting concepts through scientific practices and how these experiences shape learning such that students can develop more sophisticated understandings. The curricula, then, become part of the argument for the validity of the learning progression in that researchers can document that, with specific instructional experiences, students are able to reach more sophisticated reasoning and move to higher levels in a learning progression. Researchers can examine the pathways that students take as they develop more sophisticated understanding after engagement with the curricula, and this can inform how the intermediate or middle levels of the learning progression are defined.

Other learning progression researchers do not tie their learning progressions to specific curricula or instructional strategies. Rather, they begin with the implicit ideas that students bring to school and the upper levels or socio-scientific ideas we aim to have students achieve. The initial research tends to be cross sectional in examining how students reason at different levels across grade bands. These cross-sectional patterns in student responses, then, become part of the argument for the validity of the learning progression. Researchers then can design instructional experiences to help students move up the learning progression, documenting the progression that students take on their way to more sophisticated understandings.

The learning progression hypothesis suggests that although the development of scientific knowledge is culturally embedded and not developmentally inevitable, there are patterns in the development of students' knowledge and practice that are both conceptually coherent and empirically verifiable. Through an iterative process of design-based research, moving back and forth between the development of frameworks and empirical studies of students' reasoning and learning, we can develop research-based resources that can describe those patterns in ways that are applicable to the tasks of improving standards, curricula, and assessments.

Using Learning Progressions for Multiple Purposes

While there are certain similarities for all learning progressions (e.g., including the five essential components and beginning with students' ideas and moving toward more sophisticated and integrated understandings), there are certain choices that developers of learning progressions make in the design process. Many of these decisions are based on the purpose of the learning progression. Two important applications of learning progression research are (a) standards and large-scale assessment and (b) classroom learning and formative assessment.

Standards and Large-Scale Assessment

Past standards documents in the USA have included too many topics and separated "science processes" or inquiry from content. Although some standards sequenced the topics (e.g., AAAS Atlases), these sequences were based mainly on a disaggregation of disciplinary ideas, rather than on understandings of how students learn. The National Research Council's Framework for K-12 Science Education (2011) and the USA's Next Generation of Science Standards (NGSS) seek to use learning progression research as the basis for coherent progressions of knowledge and practice across the K-12 range. A top priority of NGSS was to provide coherent grade-band end point learning progressions such that students build deeper knowledge over time. The incomplete development of learning progression research meant that these aspirations were realized better for some topics than for others.

In order to inform standards such as NGSS and large-scale assessments based on these standards, learning progressions must describe how disciplinary core ideas, crosscutting concepts, and science practices develop over long time frames (e.g., multiple years or even K-12). Since learning progressions that can inform standards need to emphasize larger themes and patterns in how students learn these ideas, they tend to have a larger grain size, meaning that they do not include as much detail about student understanding at particular points in time. In addition, the differences among levels of achievement will likely be large, capturing major shifts in worldview or reconceptualization of key ideas.

The role of incorrect or incomplete stepping-stone levels for standards is controversial. Many would argue that there is not a place for inaccurate ideas in standards documents; rather these end-of-grade-band intermediate levels should represent conceptually accurate, but less sophisticated understandings of disciplinary core ideas that build to the upper anchor end point at the end of schooling. Thus, there is often a tension between the empirical results of learning progression research (which can show the value of noncanonical knowledge and practices as stepping-stones) and the general expectation that the contents of standards documents and large-scale assessments should be scientifically accurate.

Classroom Learning and Formative Assessment

Similar tensions can arise in classroom contexts where teachers should recognize productive (but inaccurate) stepping-stone ideas, but may still expect scientific accuracy in summative assessments. There are also differences in "grain size" between learning progressions that support standards development and learning progressions that are useful for classroom learning. Large learning progressions that stretch over grade bands are necessary to ensure coherence across K-12 education and to provide a vision for supporting students to achieving upper-level understandings. However, these broad learning progressions may not be as useful for classroom teachers as they think about responding to specific student ideas that arise in a classroom discussion or in embedded assessments, and they may not provide the support for designing activities for day-to-day or week-to-week use.

Thus, smaller, more focused, learning progressions may be helpful for developing classroom-level curricula and formative assessment. These more focused learning progressions will cover less information and the difference between levels of achievement will be smaller – identifying smaller changes in students' conceptual networks rather than large-scale restructuring. In order to ensure coherence with the larger learning progressions, these learning progressions should use the larger learning progressions in order to specify grade-band end points as their upper levels and zoom in to examine the nuances in learning to identify the middle levels or stepping-stones. Unlike learning progressions for standards, the intermediate levels for these smaller learning progressions may include the inaccurate, but productive, ideas that help students move toward upper-level understanding.

There has been significant work on learning progressions for shorter time frames that has implications for curricula and formative assessment. Researchers have used these learning progressions to develop curricula to build on students' intuitive ideas and provide structured activities that help students engage with the disciplinary core ideas through science practices. These learning progressions provide the structure for sequencing learning opportunities such that students work with specific phenomena that build more sophisticated understandings.

Learning progressions are also valuable for classroom formative assessment. By providing a model that portrays students' ideas as ranging from less to more sophisticated rather than as right/wrong, learning progressions can illustrate the range of student ideas and potential approaches to moving students forward. Since teachers often struggle to identify the range of ideas that students bring to the classroom, learning progressions can provide a structure to help teachers anticipate students' ideas and plan for how to work with these ideas. In addition, when these learning progressions are coupled with other educative tools, the learning progressions can provide a scaffold for teachers for how to provide feedback to students based on where they are on a given learning progression and can help identify ways to modify their instruction to support students in moving to upper-level understandings.

The Potential of Learning Progressions

Learning progressions of the form discussed in this entry were originally proposed as a way to bridge the gap between research and large-scale standards, curricula, and assessment programs. Because developers and researchers work under different design constraints, connections between them have rarely happened. Standards, curricula, and large-scale assessment programs need frameworks that describe learning in broad domains over long periods of time. Researchers, on the other hand, are required to develop knowledge claims that are theoretically coherent and empirically grounded. In general researchers have been able to achieve theoretical coherence and empirical grounding only for studies of learning over relatively short time spans (usually a year or less) in narrow subject-matter domains. So, faced with a confusing welter of small-scale and short-term studies, most developers have understandably based their frameworks primarily on logic and on the experience of the developers rather than empirical studies.

Current work on learning progressions has been motivated by optimism that we may be ready to bridge the gap – to develop larger-scale frameworks that meet research-based standards for theoretical and empirical validation. As such, learning progression work suggests worthwhile modifications to current procedures for developing standards and large-scale assessments. A conceptually coherent framework is an important step as the first draft of a learning progression. When researchers and developers use that framework to develop assessments and teaching experiments, and then use the results of those assessments and teaching experiments to revise the framework, we are on our way to empirically based models that can guide practice in new and more powerful ways.

Smaller grain size learning progressions can also support classroom learning and formative assessment. When they are linked to larger-scale learning progressions, they can support teachers' ambitious teaching and subsequent student learning toward important socio-scientific ideas.

Cross-References

- ▶ Alternative Conceptions and Intuitive Rules
- ▶ Conceptual Change in Learning
- ▶ Curriculum
- ▶ Designed-Based Research
- ▶ Developmental Perspectives on Learning
- ▶ Didactical Situation
- ▶ Formative Assessment
- ▶ Inquiry, Learning Through
- ▶ Longitudinal Studies in Science Education
- ▶ Model of Educational Reconstruction

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Learning Progressions, Assessment of

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Keywords

Construct map; Foundational knowledge; Instruction-assisted development; Learning pathways; Learning progressions; Teaching and learning sequences

Introduction

"Learning progressions" in science is generally defined based on the statements written at *Taking Science to School*: *Learning and Teaching Science in Grades K-8* (National Research Council [NRC] 2007) and subsequently at *Learning Progressions in Science*: *An Evidence-Based Approach to Reform* (Corcoran et al. 2009). Synthetic definition about learning progressions (hereafter LPs) addressed in common at the two reports is:

- Descriptions of the successively more sophisticated ways of thinking about and using core scientific concepts and practices
- Empirically grounded and testable hypotheses about children's learning pathways with appropriate instructional practices
- Learning pathways that children can follow one another over a broad span of time

Since the above formal addressing, there have been many studies on LPs, and at the same time, various perspectives on LPs itself and approaches to developing LPs have appeared among researchers. Thus, when we meet diverse studies related to LPs, we need to ask questions about the criteria that help to judge which LP studies are more complete and less flawed than others.

The criteria for assessment of LPs can be derived from each sentence of the definition of LPs. The first sentence allows us to assess LPs in terms of what and how LPs describe. This criterion includes selecting the topic of LPs, setting up the lower and upper anchors, and organizing the intermediate steps of LPs. The second sentence of the above definition of LPs provides two more criteria for assessing LPs: one is how to refine and validate LPs with appropriate assessment tools and measurement model and the other is how to connect instructional practices with learners' development in LPs. The last sentence of the definition of LPs gives us a criterion, how to decide the grain size of LPs.

Before looking ahead detailed discussion about assessing LPs, it would be helpful for readers to understand the above four criteria when being compared with the seven questions proposed by Duschl et al. (2011) for guiding and understanding LP research.

1. How and on what grounds have the researchers arrived at the selection of the core idea for the LPs?
2. What, if any, connections are there between the knowledge domain topic and science practices?
3. How have the researchers established the lower anchor and the accessibility of the starting point/place for the LPs?
4. How have the researchers established the upper anchor and the abstractness of the ending point/place for the LPs?
5. How, if at all, do the targeted instructional pathways/sequences serve to mediate children's learning toward the upper anchor?
6. How, if at all, do the researchers refine the LPs?
7. What, if any, alignments exist between curriculum, instruction, and assessment?

Learning progressions are generally grounded in iterative assessments that generate the evidence of children's learning pathways. Therefore, more appropriate and of high-quality LPs should show validated evidence of learning pathways as well as clear and exact assessment processes. In the next sections, it is discussed what and how LPs describe in terms of core ideas of LPs, lower anchor, intermediate steps, and upper anchor of LPs. Then an exemplary way of validation and refinement of LPs is introduced. Finally, description about the grain size of LPs and concluding remarks will follow.

Quality and Appropriateness of Learning Progressions

According to Duschl et al.'s (2011) findings, the topics in many LP studies were usually selected from and set by reviewing already established disciplinary sequences or standards and curriculum documents. Additionally, in many cases even if not all of LPs, science contents and science practices are not integrated with each other as a focused topic of LPs. The intent and goal of LPs, however, are to facilitate learners to achieve increasing levels of sophistication with using science knowledge in doing cognitive, epistemic, and social practices of science. Thus in order for more complete and less flawed LPs, the identification of foundational knowledge as a core idea of LPs needs to be clearly described. Foundational knowledge is a specific knowledge to assist and advance learning pathways of reasoning and understanding. For example, an LP for evolutionary thinking (Lehrer and Schabuble 2012) identified the foundational knowledge of change, variation, and ecosystems and conjoined using the knowledge with the practices of representation and modeling.

Lower anchor is the beginning point of an LP that represents the concept and reasoning children bring with them to school. Upper anchor is the ending point of an LP that represents societal expectations or values about what society wants children to understand at the end of LPs. Lower anchors in many LPs used to be macroscopic events or children's folk and naïve accounts related to their everyday experiences. This kind of lower anchors is easily observable, measurable, and accessible to lower-grade learners. In other cases, however, the lower anchors of LPs, which are based on curriculum documents and start at a higher grade, not kindergarten or elementary levels, are often to be at a more complex place or level. The latter cases have challenges regarding what extent children feel at ease to the lower anchors. Thus for being more complete

LPs, lower anchors should be more accessible to learners at the beginning point.

The upper anchors, in contrast, give rise to the issue of abstractness which is about the extent of complexity of targeted learning goals. Upper anchors show various forms depending on the targeted ending grade of the LPs. In one case, upper anchors tend to target college readiness. In other cases, upper anchors show the levels of knowledge and practices based on curriculum/standards documents or indicate early grades' learning goals based on scientists' own canonical conceptions. If a learning goal of LP is too sophisticated, then the upper anchor becomes too abstract or is beyond the boundaries of outcome learning expectations for children to achieve such lofty abstract goals. Thus, stronger and more complete LPs have to pay more attention to whether the upper anchor seeks for highly abstracted and scientifically accurate concepts or pursues obtainable societal expectancy for a scientifically literate citizenship.

With regard to identifying learners' developmental pathways, intermediate steps of LPs, sometimes called stepping stones, play a significant role of bridging between lower anchor and upper anchor with appropriate instructional interventions. While much of current LP research describes learning pathways based on well-grounded assessment, the instructional practices that facilitate successively increased sophistication of learning are not clearly discussed. Most of LPs, if not all, gave high emphasis on elaborating children's misconceptions in describing intermediate steps based more on assessments, less on instructional interventions. Intermediate steps in those LPs are intended to validate the initial sequences of learning and often reflect the ways by which they fix children's misconceptions and set them aligned with targeted canonical understanding. Duschl et al. (2011) referred to this perspective as *misconception-based fix-it view*, which is a prevalent characteristic of *validation LPs*. On the contrary the intermediate steps of some other kind of LPs, even though in a few cases (e.g., Lehrer and Schabuble 2012), are elicited from the results of instructional interventions employed in the LP research. The lower anchors and intermediate steps in these LPs are regarded as productive intuitions for understanding the upper anchor concepts, not as misconceptions. Thus, these LPs show practical examples of instruction-assisted development in which instructional interventions mediate learners' development working with their intuitional conceptions and practices. Duschl et al. (2011) also referred to this perspective as *intuition-based work-with-it view*, which is a feature of *evolutionary LPs*. More details about validation LPs and evolutionary LPs are discussed at the concluding remarks.

Validation and Refinement of Learning Progressions

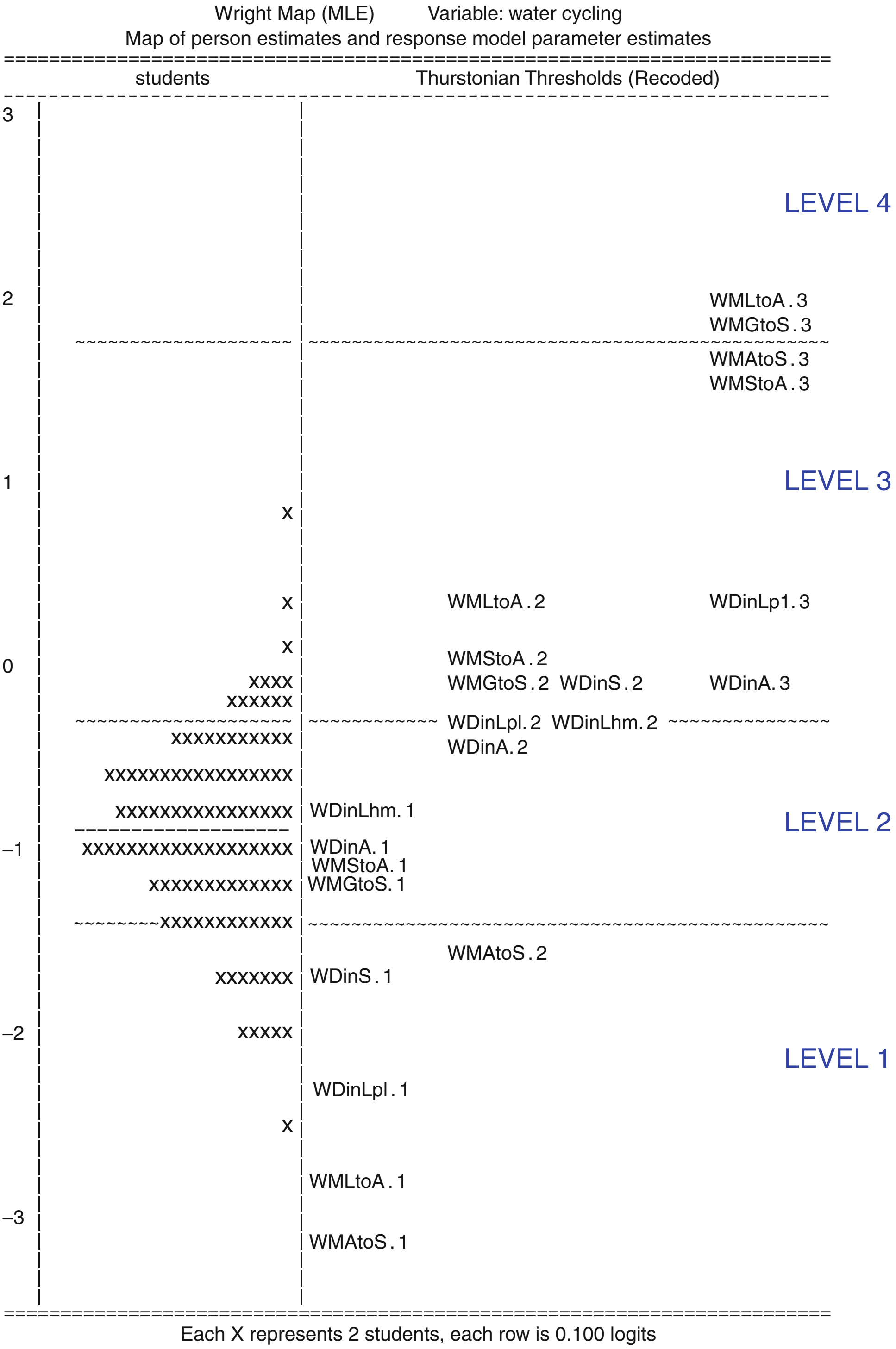
Development of LPs can be regarded as design a road map to create coherent, comprehensive, and continuous assessment systems that are interrelated with both curriculum and instruction. Berkeley Evaluation and Assessment Research (BEAR) assessment system is regarded as one of the quite suited methodological approaches to making the road maps of learning progressions, because it provides a comprehensive means for designing, evaluating, and using an assessment. BEAR assessment system also has much contributed to obtaining evidence to test, revise, and validate given hypothetical LPs with its four principles and four building blocks. Below a detailed discussion on the BEAR assessment system is addressed.

The first principle of BEAR assessment system, *developmental perspective*, is to assess the development or growth of children's understanding of particular concepts and practices over a longer period of time. This principle is operationalized by *construct map*, which is the first building block of BEAR assessment system. A construct refers to understanding of a concept or engaging in a practice that forms a substantial step in the process toward a learning goal. Thus, the construct shows a form of extension from one extreme of high quality to the other of low quality, that is, a *construct map*. In this continuum of extension of a construct, there are two aspects of construct map, a respondent construct map and a task response construct map. The former is related to where a respondent for an assessment task is located across the continuum. The latter is to show where the item responses to the tasks are located. In many LPs, the construct maps have shown only the task responses. BEAR assessment system, however, recommends depicting both respondents and task responses into one construct map. As an outset of designing LPs, construct maps can serve not only as a framework for designing assessment task items but also as a methodological base for applying a measurement model to the assessment.

The second principle of BEAR assessment system is *match between instruction and assessment*, which means the design of assessment task items should be integrated with classroom instruction. This principle is embodied by the second building block, *task item design*. There has been a variety of different types of assessment task items for describing learning pathways of LPs, e.g., ordered multiple-choice items, asking open-ended written responses, or clinical interviews. Whatever the type of task items, BEAR assessment system recommends that designing assessment items be matched to the construct maps. For example, each of the answer options in an ordered multiple-choice item is aligned with the developmental levels of children understanding described in a task response construct map. Likewise, children responses from open-ended questions or clinical interviews are coded into categories consistent with the levels of a construct map. The other and more significant consideration is the degree of match between instruction and assessment during the process of LP development. In spite of emphasis on instruction in BEAR assessment system, there is very few LP applying instructional practices to designing assessment items. Black et al. (2011) suggest a good way to align instruction and assessment, which is to develop teaching material and assessment task items at the same time. They also recommend the assessment tasks to be embedded into classroom activities as formative assessment. Considering instructional practices in developing LPs is a crucial element for more complete and less flawed LPs.

The third principle of BEAR assessment system is *teachers' management of assessments*, in which a teacher makes consistent scoring and interpretation of children's responses to an assessment. This principle is represented by the third building block, *outcome spaces*. Outcome spaces are meant by scoring guides for children responses to assessment task items. The scoring guides are in some cases (e.g., multiple-choice items) simply to assign numeric scores to each response to assessment items but in other cases (e.g., open-ended questions or clinical interviews) are to provide annotated examples for coding and categorizing children responses. In order to get a sound LP, it is very important to obtain the validity and reliability of outcome spaces.

The fourth but the most important principle of BEAR assessment system is *evidence of high quality*, which is to ensure comparability of consistent measure with various assessment tools across time and context. This principle is actualized through the fourth building block, *measurement model*. The measurement model connects scored or coded responses with the particular locations of a construct map, so that science educators or teachers can make inferences about children's learning and development. BEAR assessment system employs *Wright maps* from Rasch model as a measurement model to interpret outcome spaces of an assessment and link them with a construct map. Rasch model is a kind of one-parameter logistic model of item response theory, which estimates the probabilities of respondent proficiencies to solve assessment items compared with item difficulties. Figure 1 is a Wright map of the author's study of learning progression for water cycling with ordered multiple-choice items. The numbers arranged vertically at the leftmost of Wright map are marked out in logit (log odds unit) scale, which determine the relationship of the construct to the probability of response. On the left side of Wright map, "x" stands for two children who have specific proficiency level at its point. On the right



```
                    Wright Map (MLE)        Variable: water cycling
              Map of person estimates and response model parameter estimates
==============================================================================
               students                         Thurstonian Thresholds (Recoded)
------------------------------------------------------------------------------
  3   |                         |
      |                         |
      |                         |
      |                         |
      |                         |                                           LEVEL 4
      |                         |
      |                         |
      |                         |
      |                         |
  2   |                         |                                 WMLtoA.3
      |                         |                                 WMGtoS.3
      |   ~~~~~~~~~~~~~~~~~~~~~ | ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
      |                         |                                 WMAtoS.3
      |                         |                                 WMStoA.3
      |                         |
      |                         |
      |                         |
  1   |                         |                                           LEVEL 3
      |                        x|
      |                         |
      |                         |
      |                         |
      |                        x|             WMLtoA.2                WDinLp1.3
      |                         |
      |                        x|
  0   |                         |             WMStoA.2
      |                     xxxx|             WMGtoS.2  WDinS.2       WDinA.3
      |                   xxxxxx|
      |   ~~~~~~~~~~~~~~~~~~~~~ | ~~~~~~~~~~~~~ WDinLpl.2  WDinLhm.2 ~~~~~~~~~~~~~~~~
      |              xxxxxxxxxxx|             WDinA.2
      |                         |
      |        xxxxxxxxxxxxxxxxx|
      |                         |
      |         xxxxxxxxxxxxxxxx| WDinLhm.1
      |   ____________________  |                                           LEVEL 2
 -1   |     xxxxxxxxxxxxxxxxxxxx| WDinA.1
      |                         | WMStoA.1
      |            xxxxxxxxxxxxx| WMGtoS.1
      |                         |
      |   ~~~~~~~~~xxxxxxxxxxxx | ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
      |                         |             WMAtoS.2
      |                  xxxxxxx| WDinS.1
      |                         |
 -2   |                    xxxxx|
      |                         |                                           LEVEL 1
      |                         | WDinLpl.1
      |                        x|
      |                         |
      |                         | WMLtoA.1
 -3   |                         |
      |                         | WMAtoS.1
      |                         |
      |                         |
==============================================================================
             Each X represents 2 students, each row is 0.100 logits
```

Learning Progressions, Assessment of, Fig. 1 An example of Wright map (Reproduced with permission of the Korean Association for Science Education) side of the map, each answer option of the ordered multiple-choice items is located according to its difficulty. According to the location of each item in the Wright map, four conceptual levels among item options are differentiated. In doing so, a conjectural learning progression for water cycling could be elucidated.

Four building blocks described so far make an iterative cycle when they are applied to developing LPs. Therefore, the measurement model and its product should be employed again to revise the initial construct map, and the whole processes of developing LPs rotate again.

Grain Size and Time Spans of Learning Progressions

Learning progressions are defined as hypothetical pathways that children can follow one another over a broad span of time. Therefore, learning pathways of LPs consist of several levels with relevant time spans. The grain size of LPs refers to the amount of knowledge, skills, and ability included in each level, so that LP researchers can propose assessment items to elicit children understanding and classify children into specific levels based on the contents of each level. The grain size of LPs is also related to the distance between the levels, that is, the extent of attainment required to progress from one level to the next upper level (Alonzo and Gotwals 2012). Consequently, LPs with broader and longer time spans (e.g., K to 6 or K to 8) usually have a larger grain size than the shorter time-spanned LPs (e.g., a weeklong instructional unit). LPs with fine-grain size focus on specific and narrow conception or practice (e.g., sinking and floating), require assessment items related to a specific phenomenon in one context, and can distinguish minute differences of children's learning performances with much more detailed information used in diagnostic assessment. By contrast, coarse-grained LPs show increased amount of knowledge and practices along the more sophisticated levels, represent a greater accomplishment for moving from lower level to higher level, and require assessment items about different phenomena to characterize children thinking across contexts. The amount of contents in each level and the aspects of progress to be captured between the levels vary depending on the purposes of LPs. Thus, the grain size of LPs is to be decided by the use of LPs whether large-scale assessments, standards framework, or for a teacher's instructional units. For more complete and less flawed LPs, the balance between setting the amount of knowledge or practices in each level and capturing key differences to distinguish children's performances should be properly maintained. This balance can be achieved by iterative LP research design and empirical testing that refine the levels of LPs.

Concluding Remarks

To be a meaningful learning progression, it is very important to capture children thinking or practicing and its development accurately. An exact assessment and reliable interpretation of outcomes from the assessment provide critical information for revising and validating the learning pathways of LPs. The quality and appropriateness of LPs can be achieved by selecting foundational knowledge as a core idea of LPs, maintaining appropriate accessibility of lower anchor and abstractness of upper anchor, and applying instruction-assisted development to the description of intermediate steps. Four building blocks with underlying principles of BEAR assessment system are a useful and strong way for validating and refining a LP based on the perspective of construct map.

Duschl et al. (2011) marked out two types of LPs, validation LPs and evolutionary LPs. *Validation LPs* are to confirm or validate preliminary established teaching and learning sequences with assessment tools. Instructional interventions in validation LPs are designed to revise the original learning sequences adopting misconception-based fix-it view of conceptual change model. Thus validation LPs are regarded as top-down and theory-driven LPs. *Evolutionary LPs*, on the contrary, typically begin with pilot assessments to explore and identify successive patterns in children's understanding of concepts and practices. Delineating a construct map based on the successive patterns is a way to obtain evidence of evolutionary development of children learning. Evolutionary LPs also establish a conjectural pathway of learning based on the consequences of instructional experiments across multigrades adopting intuition-based work-with-it view of conceptual change model. Thus, evolutionary LPs are regarded as bottom-up and evidence-driven LPs. Duschl et al. (2011) argued that only the evolutionary LPs can articulate plausible incremental learning pathways with instruction-assisted development and can be complete, at least near complete, and appropriate LPs.

Cross-References

- ▶ Achievement Levels
- ▶ Developmental Perspectives on Learning
- ▶ Learning Progressions
- ▶ Proficiency Levels
- ▶ Teaching and Learning Sequences

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Learning Science in Informal Contexts

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Creative thinking; Informal learning; Informal science education

Learning for Life

A growing body of evidence supports the assertion that learning occurs in settings and situations outside of school, as well as across time and a variety of settings (Falk and Dierking 2010). This increased appreciation of free-choice/informal learning is affording learners increasing choice and control and is a worldwide phenomenon. Although this type of learning has traditionally been referred to as informal learning, Falk and Dierking coined the term free-choice learning almost 20 years ago to capture the core idea behind this paradigm shift – a recognition that people not only learn every day throughout their lives but that learning is, first and foremost, a learner-centered, not an institution-centered, phenomenon. Free-choice learning is guided by a person's needs and interests and is nonlinear, self-directed learning. People engage in free-choice learning throughout their lives to find out more about what is useful, compelling, or just plain interesting to them.

Science learning is an important part of this educational shift. People engage in science learning every day and across their life spans – at home, at work, and while out in the community; much of this learning is free choice. In a typical day, for example, a person might surf the Internet in a library to track down information about arthritis, attend an amateur astronomy club meeting, watch a nature documentary on television, or interact with exhibitions on robotics at the local science center. All represent free-choice learning experiences, the most common type of learning in which we engage throughout our lives. The senior citizen who has been an avid bird watcher across his/her lifetime, keeping a life list of birds, going on trips focused on bird watching, reading as many books and magazines as possible, as well as watching documentaries on birds, is also an example of a lifelong free-choice science learner.

A recent study by the National Research Council on learning science in informal environments (Bell et al. 2009) reinforces the abundant evidence that free-choice learning activities, even everyday experiences such as a walk in the park, contribute to people's knowledge and interest in science. For example, adults visit settings such as national parks, science centers, and botanical gardens to satisfy their intellectual curiosity as well as to fulfill a need for relaxation, enjoyment, and even spiritual fulfillment (Falk 2006). Adults take their children to these settings because they feel such experiences are worthwhile, educational, and fun and that they and their children learn about science in the process.

Adults also encourage their children to participate in a wide variety of after-school and extracurricular experiences, including scouting and summer camp experiences, many of which also support free-choice science learning (e.g., McCreedy and Dierking 2013). Adults and children also learn while engaged in personal investigations, through civic organizations and active leisure pursuits. Similar motivations and findings can be ascribed to watching science-related television, using the Internet to access science-related information, and engaging in science-related hobbies and special interest groups such as birding, gardening, and hiking.

This paradigm shift suggests that to effectively understand science learning, one must situate it within the context of lifelong learning. The most important aspect of this perspective is that science learning is viewed as a natural and fairly common result of living within a science-rich world, an activity and outcome of everyday life. Over the course of a lifetime, a person constructs his/her understanding of the world by connecting and building upon experiences they have in school, at work, and in informal/free-choice learning settings and configurations. This cumulative process not only involves learning facts and concepts, though important, but also includes changes in interest, awareness, skills, behavior, attitudes, beliefs, habits of mind, and feelings and emotions (Bell et al. 2009). Such learning may result because the learner was "primed and ready" for transformation through previous experiences or because unique experiences are so powerful that significant changes result.

Although free-choice learning significantly contributes to what is learned in an individual's lifetime, currently it represents a fraction of the learning research literature. Exacerbating this situation, the research is scattered across many disciplines and subdisciplines, with few efforts to consolidate, situate, and synthesize it within an overall framework. Fortunately, a growing body of research is providing evidence for such learning. If one looks at basic and applied research, what is revealed are three, essentially independent lines of investigations, which evolved during the last quarter of the twentieth century: (1) how people learn in out-of-school institutional settings like museums and libraries; (2) how people learn through media-mediated experiences (e.g., television, gaming, Internet); and (3) how people learn through nonformal learning, particularly as it occurs in unstructured/cultural contexts.

Institutional Settings

Museums One of the first settings in which free-choice learning was seriously investigated was the museum. For example, in the 1930s, Arthur Melton, under the direction of Yale professor Edward Robinson, conducted two landmark studies of behavior and learning in art museum settings. Then, as today, these psychologists viewed museums as useful laboratories for studying learning – free-choice yet structured environments. With the notable exception of the groundbreaking book, Unobtrusive Measures in 1966, which utilized a number of examples from nonschool institutional settings, it was nearly

40 years before additional serious research was conducted in these settings.

Beginning in the mid-1970s and building momentum through the 1980s, a series of investigations were conducted on learning in institutional free-choice settings; many of these were doctoral dissertations. By the 1990s and into the 2000s, research on learning in these venues had become commonplace, particularly in science museums. There were important studies over the last 15 years, some again dissertations, including multiyear studies of family learning in science museums and ethnographic research on the role of museums in supporting family's long-term learning, the investigation of children's science concept development in a children's museum, the impacts of school field trips to museums and of visits to zoos and aquariums on visitors' and staff members' understanding of conservation, as well as investigations into identity and the long-term impact of visits (Falk and Dierking 2013).

Another avenue in which free-choice learning has been observed is through community-based institutions/organizations such as Boys & Girls Clubs, scouts, YMCAs/YWCAs, etc. Most often these efforts focus on families, youth, and children living in poor urban or rural communities; many are recent immigrants for whom the mainstream language is not their first. Most of these learning opportunities involve in-depth programming in the community in which participants live, however often complemented by programming within a cultural institution such as a museum. Research suggests that these efforts are extremely effective when integrated with trusted community-based organizations that share a common goal of supporting families, youth, and communities. Much of the research has focused again on science, finding that after participating, families and youth better understand processes of science and its importance, develop enriched conceptual understanding and a stronger sense of science's role in their daily lives, and appreciate that science is not about "getting the right answer" but wondering, asking questions, and experimenting. Two common outcomes for programs with museum components include an increase in museum interest and/or attendance, at least in the short term, and positive changes in participants' perceptions of museums. These programs also help participants understand that museum programs offer fun and comfortable ways to share quality time together. Since many programs focus on families, outcomes for adults are also observed; for example, they include increased parental awareness and involvement in their children's (and their own) learning, as well as a better understanding that learning is not just for children but for them also and that learning together as a family can be enjoyable and rewarding.

Although efforts also often try to engage families in other kinds of free-choice learning outside the program, these impacts are much less commonly observed. Community events may encourage active participation, but it is difficult to encourage parents to continue activities with children at home. Participants do identify a main benefit as "expanded horizons" or "exposure to culture." The evidence that is available suggests that families engage in learning experiences that build on the program, including related conversations at home and family visits to other similar places. There is still insufficient data to determine whether impacts from these efforts are lasting. For instance, in programs encouraging museum use, it remains to be seen whether use continues once the program ends.

Libraries These societal trends are also directly influencing libraries, and as with museums, staff and researchers are attempting to better understand library users. Most libraries know "why" the public uses them, appreciating that they have long been viewed as beneficial to children and considered to be safe and educational places. In fact, a recent report concluded that libraries positively contribute to youth development. Over two-thirds of parents say they take their children to the library, and a common reason adults say they visit is for their children. Early experiences with visiting libraries may be a factor in adult library use, as is the case in other free-choice learning environments such as museums and zoos.

Adults alone or visiting with children primarily visit libraries to borrow books and use reference materials, much of this science focused. Accordingly, libraries have worked extremely hard to understand how to meet their users' resource needs. Many libraries strive to enhance the public's information literacy, and considerable research has been conducted on how libraries can best respond to the wide range of information needs of the public. This research has been used to assist users in more effectively accessing the information they seek; however, there have only been a few efforts to assess the impact of public libraries and to understand how access to library resources directly influences users' learning needs, generally, and their science learning needs more specifically.

Researchers have found that people feel libraries contribute to their quality of life as a source of educational (98 %) and cultural (84 %) enrichment and entertainment (87 %) and are important because they are free (48 %). In a 2001 Institute of Museum and Library Services (IMLS)-funded impact study, Counting on Results (http://www.lrs.org/documents/cor/manual2.pdf), over 5,000 library users in 20 states completed mail-in questionnaires related to various service categories – basic literacy, business, and career information, library as a community hub, and so on. Over half of those responding (56 %) said they used the library for self-directed learning; however, the methodology did not allow researchers to probe this aspect of library use in any depth. Other studies have assessed library programs' outcomes and impacts on participants, but the focus of the studies was primarily on the impact that established library programs, such as adult literacy programs and homework help, had on the individual and did not specifically probe impacts of self-directed learning activities.

An environmental scan conducted by the Online Computer Library Center (OCLC; http://www.oclc.org/en-AU/reports/escan.html) in 2003 suggested that libraries are poised to reassert themselves as core lifelong learning institutions by capitalizing on their primary assets as "trusted" and "safe" gateways to information. The scan also identified three characteristics that those who use libraries desire: self-service, seamlessness, and satisfaction. The study suggested that an important step in this transition is to redefine the library as an active hub of personalized, free-choice learning, shifting from being dispensers of information, to becoming facilitators of the personal learning journeys of their users. To do so effectively, though, libraries must better understand the public's perceptions of their institutions and how they are used (or not used) for lifelong, free-choice science learning.

A 2007 study explored whether a more personalized approach to serving library users is a useful framework for the library community (Falk et al. 2007). Findings revealed seven common identity-related library user motivations that are similar to Falk's identity-related visitor motivations for museums. This study recommended the development of a set of "bundled" offerings and strategies enabling libraries to meet the identity-related needs of a wide variety of users, including frequent, occasional, and infrequent users. As recent research in museums has shown, most visitors rarely explicitly share their needs or even can fully articulate them; arguably the same is true for library users. Also, museum research has demonstrated that although visitors familiar with museums may be able to seek out a specific resource, those less familiar often are unaware of the broad range of offerings available, making them functionally nonexistent. These research findings reinforced this; even frequent library users mentioned offerings that they wished the library had that were in fact, available. If savvy library users are unaware of possible offerings, one can only imagine that new audiences, such as newly arrived immigrants and other underserved groups who may not have historically used libraries as resources, might also be unaware.

Media

The early days of research on media were dominated by studies of television, in particular related to issues such as media preferences, health (e.g., impact of television viewing on vision), and social concerns (e.g., impact of television on violence and consumer behaviors). By and large these topics dominated research in this area for decades. However, starting in the late 1970s/early 1980s, a number of investigators, in particular those studying Children's Television Workshop Sesame Street programs, began a series of comprehensive investigations into the impact of television on children's learning and cognitive development. Although the focus of a majority of these investigations continued to be the impact of television on children's school achievement, a smattering of these studies focused on learning impacts beyond schooling – including issues such as generalized literacy, creativity, and children's self-regulation and self-esteem.

More focused studies of media impacts have been conducted in the last decade, particularly studies of media in general, and specifically television, and more recently the Internet. Much of this research has focused on public understanding of science. Studies in this area basically fall into three broad categories: (1) generalized investigations that document the differences and consequences between learning in and out of school, (2) studies that have focused on the role of media in shaping public understanding of science, and (3) studies that have investigated more fine-grained impacts of media use. These studies have identified television as the most frequently used science information source – especially information about the environment – even though most citizens and social scientists question the reliability of some of the information provided. In 2006, the Pew Research Center's Pew Internet and American Life Project (http://www.pewinternet.org) reported that the Internet had replaced television as the primary source of the public's science information.

A range of more fine-grained investigations of science learning and media use have also been conducted. These include how public television programs influence children's problem-solving behavior; young children's viewing behavior and information-acquisition skills such as sequencing, patterning, and creative thinking; and, more recently, efforts to determine how digital media can be used as effective learning tools.

Despite its obvious importance, over time research into the role of media in supporting free-choice learning has remained at a relatively modest level. We know that television and the exploding arena of new media including the Internet, video games, iPods, and handheld devices have a tremendous impact on the public, with evidence that children and adults learn a great deal from their use. Relative to the importance of these media in society though, the quantity of research on their impacts on free-choice learning remains inadequate. In particular, with the spread of the Internet and the growing ubiquity of wireless mobile networks, a new generation of informal/free-choice learners, many young, are growing up in a "wired" world. Referred to as "millennials" (i.e., graduated high school in 2000) and sometimes called "digital kids," these youth are avid consumers of traditional media, electronic games, and Web-based information. In the United States in 2002, more than 78 % of children between 12 and 17 years went online. This has grown to 95 % in 2013 (http://www.pewinternet.org/Reports/2013/Teens-and-Tech.aspx). These youth use digital tools in their everyday activities not only for communication, school assignments, way finding, and play but also to create and exchange personally meaningful messages, tools, and digital media products across distributed social networks and online communities. Raising the ante even more, digital media production and free Web-based authoring tools enable youth to create multimedia stories, join online hobby communities, and create personally meaningful virtual objects in 3D online worlds, thus providing these learners even more ways to personalize and control their own learning. While using these tools, millennials are developing habits of multitasking, comparing multiple information sources, and trying out new virtual identities. They also gather, design, critique, synthesize, and develop movies and other digital products, all requiring technical expertise and digital fluency skills and competencies such as an understanding of design approaches and new representational practices.

Though Internet and online media use by youth is more commonly documented and researched during school hours, one would expect these tools to be used even more outside school, given that youth have more free time and opportunities for technology access through libraries, friends, and Internet cafes. This would seem to suggest that investigations into how these tools are used by youth during their out-of-school time would represent a fruitful arena in which to conduct research. Currently, though, there are no systematic longitudinal studies of youths' cumulative experience with digital media from childhood to adulthood or setting to setting nor an understanding of the cumulative effects of digital media upon cognition, learning, and development. This means there is little understanding of the role these tools play in supporting independent/free-choice (and compulsory) learning among youth. When the majority of practice and interaction occurs in extended virtual social worlds across multiple physical and online settings outside formal confines, research can be challenging, but it is critical that we begin to tackle the challenge. The realization that learning spaces do not exist in isolation is important in an age in which technologies make it not only possible but increasingly likely, and even natural, for learners to not be confined to a particular learning space. When such seamlessness becomes the norm rather than the exception, it is important for researchers to understand how different learning experiences and spaces are connected as part of a wider learning ecology, rather than merely focusing on what happens within a particular learning space, be it formal or informal.

Nonformalized Learning

In the mid-1970s, Scribner and Cole (1973) wrote a seminal paper that argued for increased emphasis on investigating learning outside the formal education system. According to Scribner and Cole, virtually all the research and theorizing about learning up to that point had focused upon schooling which they felt in the industrialized world in particular was a very specific lens, emphasizing didactic, rational, and "scientific" approaches to learning. They pointed out that much of learning occurred in everyday situations, and rather than being viewed as an ineffective substitute for formal learning, these typically culturally situated and often modeled forms of learning were quite effective.

Scribner and Cole's ideas inspired a whole line of investigations dominated by social psychologists, anthropologists, and sociocultural researchers, fostering a small but steady range of interesting studies occurring over the past 30 years. Arguably, the greatest contribution of this line of research has been the documentation that sophisticated learning takes place in communities without formal learning instruction. Particularly important has been the work of Greenfield and her colleagues in rural Mexican communities demonstrating the sophisticated learning of weaving skills (Greenfield and Childs 1991). Other studies have investigated the use of everyday arithmetic by housewives while grocery shopping and Brazilian street children's everyday mathematical abilities (Saxe 1988). Building on this model, free-choice learning researchers have begun to study learning in everyday settings such as family learning in the home.

Overall, investigators working in this area have been able to document two very important claims relative to learning. The first is that informal modes of learning are extremely powerful and pervasive. Equally important, researchers in this area have pointed out that a major premise of formal education, namely, that it is the best strategy for teaching generalizable and transferable knowledge, is significantly flawed. Investigators have been able to demonstrate that all learning is contextual, not merely that learned outside of school. This suggests that what school children learn in formal educational settings is strongly tied to the nature of that setting and not necessarily generalizable beyond that educational context.

Discussion

Several conclusions from this review of free-choice science learning are warranted. First, considerable research has been conducted in all three of these areas – institutions, media, nonformal – and other areas also, though of far more modest scope and scale. That said, until very recently, the interactions between these three main lines of research have been relatively few, with little cross-fertilization of ideas, methods, or findings. As these brief reviews point out, there is a tremendous need to foster collaboration between these lines of inquiry. Researchers and practitioners in these communities have been investigating similar questions yet in many cases using different approaches and frameworks for study, and much has been missed historically by the lack of communication among them.

There is much to learn from the diverse perspectives and approaches each group has taken and much to be gained in the future if these lines of research were more closely aligned. As educators strive to develop public interest, knowledge, and understanding, they need to be aware of the vast number of ways, ages, and places in which persons learn across their lifetimes. In the twenty-first century, free-choice learning institutions such as museums, libraries, the Internet, and broadcast media, to name but a few, are assuming an ever more prominent role in lifelong learning. These experiences represent important, in fact essential, ways that people learn and most importantly contextualize their science knowledge and understanding. As learning researchers and educators in the twenty-first century, it is critical to move beyond rhetoric to recognize, understand, and learn how to facilitate free-choice learning as a powerful vehicle for lifelong learning – not as a nicety, or a supplement to the learning engaged in at school and university, but as an equally essential component of lifelong learning. To not understand and embrace this form of learning as a valuable component of education in the twenty-first century is to seriously impede one's ability to enhance learning.

To enhance lifelong learning effectively, three aspects of this enterprise must be considered: (1) awareness and recognition of the learning infrastructure in each community, (2) the need to create a corresponding infrastructure for education and research that supports the facilitation of this type of learning and its connections to other forms of learning, and (3) a clear vision of the research directions that will be most fruitful and productive.

The Learning Landscape. Although it is not a large conceptual stretch to envision a complex community infrastructure of science learning resources that supports and facilitates the learning that takes place there, it is quite another thing to understand how it actually functions on the ground for learners. This basic learning infrastructure already exists in almost every community, including traditional constituents such as schools and universities, print and broadcast media, libraries, museums, zoos, aquariums, community-based organizations, and the workplace. However, increasingly these institutional constituents are being supplanted by noninstitutional, more fluid entities such as hobby groups and social networks, both virtual and physical. Currently, there is little understanding of how this learning infrastructure functions and how the various components intersect and interact. As the historical distinctions between formal and informal education are increasingly blurring, it is essential to better understand the basic nodes of the learning infrastructure and how these nodes interconnect from community to community. In short, investigations about the structure and functioning of the learning landscape/infrastructure should be an important element of any future research endeavor.

Historically, investigations of learning have been quite bounded. Most studies have investigated specific age cohorts, within classrooms, over the time frame of a unit or at most a school year. Even investigations of free-choice learning have typically been equally bounded, e.g., visitors to a specific museum, often a single exhibition, framed by the duration of a single visit. However, what is known about the nature of learning suggests that it is rarely instantaneous and does not occur in one place at one time; instead learning is strongly socioculturally framed and cumulative. The scope and scale of investigations need to be expanded in order to better encompass the realities of lifelong learning. This will require different methods, different questions, and different types of financial investment. It also will require new partnerships between organizations and individuals – partnerships that better reflect the actual structure and functioning of where and how the public learns.

An Ecology of Learning for Life. Throughout the twentieth century, the focus of learning investigations was top-down with a focus on instruction and curriculum. The organizing framework was that institutions should and could provide all that was necessary for an informed, literate citizenry. While there is increasingly greater openness toward learner participation in structuring learning experiences and the environments in which they take place, the learner is still basically expected to accept the package as it is offered. The learner is the consumer of a ready-made or, at best, partly customizable product.

This is not the reality of the twenty-first century. Learning in general, and science learning specifically, is increasingly becoming bottom-up, controlled by the individual and highly focused on meeting personal needs and interests. This shift has huge implications for not only how learning occurs, but how research on learning should be conducted. In the new world order, the learner's role is quite different. Although the reasons for learning may sometimes still be associated with the pursuit of formal learning objectives or career goals, the majority of self-directed independent learning will be aimed at meeting identity-related needs unassociated with degrees and employment – instead learning will be associated with hobbies, personal curiosities, or individual needs such as environmental/historical preservation in the neighborhood or responding to health issues. One approach to this perspective is the argument that learning entities at different levels of organizational complexity – ranging from the individual to the social – behave like complex adaptive systems (CAS). Thus to understand learning, it is crucially important to recognize the ecological wholeness of the learning environment and allow these entities to self-(re)organize themselves perpetually, in a Web of nested frameworks relevant to different time frames and spatial contexts for human learning.

A Clear Vision for Research. If the goal is to embrace a broader notion of learning situated within an ecological system, it is critical to identify what researchers might be looking for, where to start looking, and how to look. Two broad lines of research are envisioned. The first is a top-down view that attempts to deeply understand the structure and functioning of the ecosystem, existing, as well as potential, interrelationships between actors and agents in the learning landscape. The second is a bottom-up view that begins with the learner and attempts to deeply understand their own ecology of learning from a learner-centered perspective. Both of these lines of inquiry will require teams from multiple disciplines and will be more robust if they involve both researchers and practitioners and occur across extended time frames (5–10 years).

In conclusion, whether one uses these ideas or others, the take-home message is that future investigations of learning need to situate the learner at the center rather than the periphery of the learning process. In order to meaningfully understand what learning is but even more importantly why it happens, studies also should frame science learning within the larger ecological context of an individual's life and the learning landscape in which they live. Taken together, increasing an emphasis on free-choice science learning and its connection to other aspects of the learning landscape holds the promise for more effectively understanding and achieving measurable, long-lasting impacts on the public's understanding and interest in science, learning for personal fulfillment as well as for an informed citizenry.

Cross-References

- ▶ Aquaria
- ▶ Botanic Gardens
- ▶ Broadcast Media
- ▶ Family Learning
- ▶ Hobbies
- ▶ Lifelong Learning

- ▶ Museums
- ▶ Print Media
- ▶ Visitor Studies
- ▶ Zoological Gardens

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Learning Theories and Models

- ▶ Activity Theory and Science Learning
- ▶ Constructivism: Critiques
- ▶ Didactical Contract and the Teaching and Learning of Science

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Legitimate Peripheral Participation

- ▶ Communities of Practice

Lesson Study Research and Practice in Science Classrooms

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Definition of Lesson Study

The publication of *The Teaching Gap* (Stigler and Hiebert 1999), based on the TIMSS Video Study of grade 8 mathematics classrooms in Japan, Germany, and the USA, led to an interest among educators across many disciplines in Lesson Study – an important part of Japanese teachers' continuing professional development. "Lesson Study" is a literal translation of the term *Jyugyou kenkyuu*. *Jyugyou* means lesson, and *kenkyuu* means study or research. Lesson Study is a comprehensive and well-articulated approach to examining practice that many Japanese teachers engage in. The process involves a critical focus on the relationship between teaching and student learning.

Lesson Study is historically and strongly embedded in Japanese teachers' professional culture in both pre- and in-service teacher education (e.g., Isozaki and Isozaki 2011). The origin of Lesson Study can be traced back to the Meiji era, particularly the 1870s and 1880s, following the Meiji Restoration in 1867. Lesson Study was standardized by the end of the nineteenth century, and the process has evolved since then. Recently, in the USA and elsewhere, attempts have been made to theorize Lesson Study, something which had not taken place in Japan itself.

Processes and benefits of Lesson Study

Lesson Study may typically be divided into three parts: preparation, research lesson, and reflective meeting/conference. In initial teacher education, Lesson Study takes place during teaching practice in school. Student teachers are encouraged to participate in practice within a professional community that includes experienced teachers (mentors), other student teachers, and the school students themselves. The process focuses on various dimensions: what teaching involves, what the teaching profession is, how to carry out lessons under the instruction of a mentor and a university tutor, how to make a lesson plan and a scheme of work, and how to research and develop teaching materials. Student teachers observe their mentor's model lessons and attend lectures on the mentor's views of teaching and classroom management. Student teachers collaboratively make a lesson plan and also research and develop teaching materials based on discussions with other student teachers and on advice from their mentors. Student teachers take part in a reflective meeting/conference with their peers after a research lesson given by one of the student teachers. This process is repeated throughout the students' teaching practice. Through this process, student teachers gradually become familiar with the processes and benefits of Lesson Study including researching and developing teaching materials.

Preparation usually involves participants defining the problems and deciding the theme and the goal of the Lesson Study. The teachers collaboratively plan the lessons: the type of lesson, the teaching content, the focus, the teaching materials, the practical activities, the assessment of student performance, etc. One way to conceptualize Lesson Study is to see it as a process that starts with questions, whereas professional development workshops often start with answers.

Science teachers often try to find new and appealing teaching materials focusing on investigations using practical activities. In researching and developing teaching materials and making a lesson plan, pedagogical content knowledge (PCK) plays an important role. The teacher who will give the research lesson makes and revises a lesson plan based on discussions with colleagues and advisors, e.g., consultant teachers of a local board of education and university professors. In general, a lesson plan includes the objectives; the main scientific ideas of the unit; student characteristics, including their prior knowledge and preconceptions; the overall scheme of work; and the structure of the 1-h lesson which includes a description of what might happen during the hour. Assessment tasks, including criteria and methods to be used during the whole unit and for every lesson, are added to the plan (see Fig. 1).

The 1-h lesson structure described in the lesson plan format is basically divided in three columns: time and phase, students' activity and learning with anticipated student responses, and teacher's activity including assessment tasks. Students' activity and learning are always at the core of teachers' professional judgment and pedagogical decision making. As a result, the lesson plan provides the teacher and observers with a platform that includes the scientific and educational values implicit and explicit within the lesson.

The teacher gives the research lesson in the classroom based on the lesson plan developed by the above process. Other teachers use the revised lesson plan as a guide for their comment on and critique of the lesson. They collect data and take notes focusing on the teaching and on student learning. The other teachers sometimes move around the laboratory to listen to what students are discussing, to observe how students are engaging in practical activities, and to check what students are writing on their worksheets. Most science teachers who give a research lesson are eager to use an inquiry-based approach encouraging students to make predictions or hypotheses, conduct practical activities, obtain data, and induce a law or principle from these data. The use of video cameras for recording the research lesson enables teachers to reflect on their teaching and to analyze the students' activities.

A reflective meeting is usually held later the same day and is based on the evidence collected during the research lesson. Outside advisors, who also observed the lesson, attend the reflective meeting in order to give comments and advice. Sharing the results through Lesson Study can be done in several ways including writing a report or a school bulletin. These documents provide a record of Lesson Study for future use.

Grade ○ Science Lesson Plan

Name of teacher:
Date and time: yy/mm/dd, time
Place: laboratory or other places
Class:

[Unit title]

[Unit objectives] Based on the Course of Study and teacher's ideas, student should know and understand, be able to, etc.

[Views of unit]

(1) Main ideas of the unit and the key teaching contents,

(2) Learners' characteristics and their prior knowledge and preconceptions relating to this unit, and classroom atmosphere,

(3) Teacher's view and ideas for instruction based on both 1) and 2).

[Assessment tasks] Criteria and methods of the whole unit and each lesson.

[Overall Scheme of work] The sequence of unit goals with the number of hours to be spent on the unit.

[Today's one-hour lesson]

(1)Title of topic

(2) Objectives of today's lesson

(3) Resources

(4) Development of today's lesson

Time and phase	Students' activity and learning based on anticipated students' response	Teacher's activity including assessment tasks and notes
(Minites) [Introduction] [Development] [Conclusion]	[Review of previous lesson] [Some questions and anticipated answers] [Practical activities and anticipated errors] [Students' presentation and anticipated results] etc.	[Points to keep in mind] [Assessment tasks: criteria and methods including supports for lower achieved students] [Safety] etc.

Lesson Study Research and Practice in Science Classrooms, Fig. 1 An example of lesson plan in Japan

Lesson Study and Professional Development

Teaching is a complex cultural activity and the classroom can be chaotic and unpredictable. Lesson Study has features similar to other forms of pedagogy of investigation in teacher education; however, it has its own unique characteristics. For example, in action research a teacher examines their own teaching and their students' learning by engaging in a research project in their classrooms, with working with colleagues being usually optional. On the other hand, Lesson Study emphasizes that the process involves collaboration with colleagues and a common focus (e.g., Stepanek et al. 2007). Therefore, Lesson Study can build effective collegial relationships in a school, and the results can be reflected in everyone's teaching. Through Lesson Study, collaboration within a professional community is seen as a useful vehicle for teachers to improve their teaching, and it can help to reduce feelings of isolation.

Lesson Study helps to foster the learning or professional community in and between schools. The approach helps to form a teacher culture which provides opportunities to share the dominant values of science education. However, the approach can be a double-edged sword: there are both benefits and disadvantages, e.g., while Lesson Study is a useful vehicle to spread an "ideal model" of teaching science which many science teachers may adopt, lessons may become more standardized and the values shared by science teachers sometimes lag behind the latest research trends. Professional growth in Japan is naturally embraced by teachers and is encouraged not only through Lesson Study but also through other learning activities which take place in the daily life of the school and through reflective conversations on scientific and educational issues among teachers. These important and traditional features are based on a professional culture which promotes effective continuing professional development.

Cross-References

- ► In-service Teacher Education
- ► Pedagogical Content Knowledge
- ► Teacher Professional Development

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Lifelong Learning

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The nature of science learning is changing worldwide as individuals have unprecedented access to science education opportunities from cradle to grave, 24/7, through an ever-growing network of educational opportunities in and out of school. The most rapidly expanding are opportunities beyond schooling which include visits to museums, zoos, aquaria, science centers, natural area parks and preserves, television, radio, films, books and magazines, and increasingly through personal games, podcasts, the Internet, and other social networking media. A hallmark of this revolution in science learning is that collectively these organizations and tools enable a growing number of individuals to customize and take charge of their own learning. Learning can no longer be divided into a place and time to acquire knowledge (i.e., school) and a place and time to apply the knowledge acquired (i.e., the workplace). Instead, learning is increasingly appreciated to be something that takes place on an ongoing basis from our daily interactions with others and with the world around us. Individuals learn science for multiple reasons, including in order to further their careers or for personal advancement, to build social relationships, to meet external expectations, to seek escape/stimulation, and to satisfy cognitive interests and curiosities; from this perspective it can be seen that the vast majority of science learning is a free choice, in other words, "learning for the sake of learning" (Falk and Dierking 2002).

Individuals engage in various forms of science learning nearly every day – at home, at work, and while out in the community. Although considerable time and energy have been invested in understanding the public's science learning, including what people know and understand and how they come to acquire that understanding, historically most investigations have failed to recognize the contingent, lifelong, and diverse experiences that support engagement with and learning of science, in both formal and informal environments. In short, it is not the one-off, individual experiences that matter as much as the sum totality provided by those engaged in science education across the course of their life.

A number of countries have begun to advocate for the importance of lifelong learning in order to create an enriching and dynamic society. They see lifelong learning as a fundamental human right and social justice issue. As such, they view learning in general, and science learning in particular, as a process that not only enhances social inclusion, competitiveness, and employability but also active citizenship, personal fulfillment, and development.

From this perspective, science learning opportunities should be available to all citizens on an ongoing basis. In practice this should mean that citizens each have individual learning pathways, suitable to their needs and interests at all stages of their lives. The content of learning, the way learning is accessed, and where it takes place may vary depending on the learner and their learning requirements. This means that across the board, science learning opportunities need to become much more open, flexible, and responsive so that such opportunities can truly be tailored to the needs of all current and potential learners.

Basil Yeaxlee (1929) is usually credited with being the first modern writer to fully develop the idea of lifelong learning and education. He, along with fellow pioneer Eduard Lindeman (1926), provided an intellectual basis for a comprehensive understanding of the importance of supporting education as a continuing aspect of everyday life. They drew their ideas from numerous sources but were strongly influenced by the ideas of North American educational thinker John Dewey. In more recent years there has been a shift in the conceptualization and implementation of lifelong learning from notions of "continuing" education for adults (typically occurring in formal contexts) to the ideas of "continuous" education for all learners (across a wide range of settings and contexts) described in the opening paragraphs.

Cross-References

▶ Learning Science in Informal Contexts

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Longitudinal Studies in Science Education

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Keywords

Cross-sectional studies; Learning progressions; Longitudinal studies; Long-term processes; Research designs; Retrospective studies; Trend studies

In research terminology, the adjective "longitudinal" refers to features of research designs for studies conducted over time. Since education is a gradual process with long-term goals, such studies are essential to elucidate what happens, how, and why. This entry offers a working definition for longitudinal studies and discusses *"true" longitudinal research designs* that are the gold standard for investigating continuity and change. They are juxtaposed with complementary *trend*, *retrospective*, and *cross-sectional* research designs. The entry makes comments on published longitudinal studies in science education, and attends to the persistent issue of insufficient research-based knowledge across themes along the time dimension.

Working Definition for Longitudinal Studies in Science Education

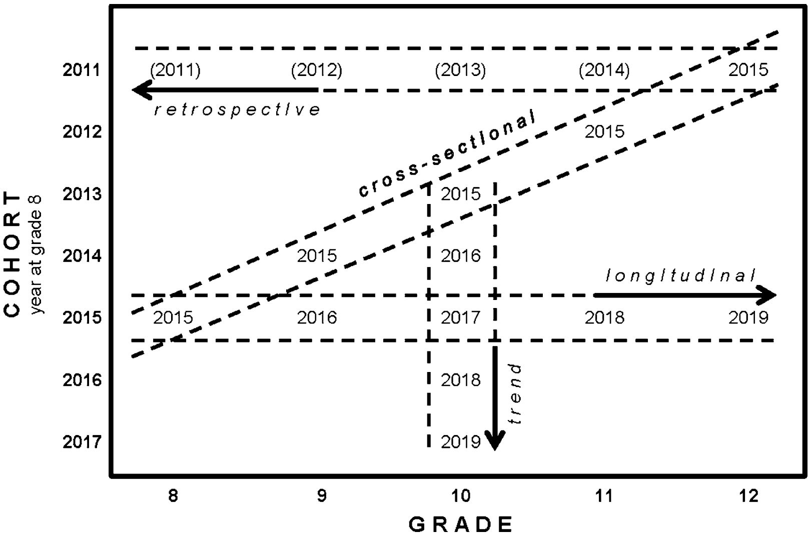
The established tradition of longitudinal studies in the behavioral and social sciences accepts a range of quantitative and qualitative designs, yet there is a sine qua non: In a longitudinal design, data on the investigated entity are collected at more than one point in time. The inclusive term "investigated entity" acknowledges that studies are not restricted to human subjects, for example, reform sustainability can be investigated through comparisons between reform-related outcomes over several years. Comparability of data over time is imperative for valid inferences on continuity and change. An extreme perspective demands identical procedures at all data collections, but this may introduce interferences and may not be possible (e.g., when instruments should be adjusted to student age). The time span of data collections depends on research questions and can reach decades, as in explorations of life-course and generational shifts in developmental psychology and sociology. In science education, an adequate minimum for categorizing a study as longitudinal is one calendar year, because during this period the boundaries of a school year are crossed and educationally significant transitions occur in regard to curriculum materials or mobility of students and teachers.

The above clarifications underlie a working definition that applies to science education: A longitudinal study collects comparable data on the same entity at least twice over a time span of at least one calendar year.

"True" Longitudinal Research Designs

In a *"true" longitudinal research design*, the same subjects are actually followed over time. Subjects are often investigated as part of a group of members with a common trait, referred to as *cohort*. In science education, cohorts usually share a chronological stage: students at the same age or school grade; teachers with similar experience or participating in a program during the same year. A study may follow more than one cohort, as happens in evaluations with experimental and control cohorts. The label *cohort designs* is sometimes used, while the label *panel designs* applies to the general case of groups that are not identified a priori by common traits, though the analysis can differentiate between age, gender, ethnicity, etc. The occasions or periods of data collection are known as *waves*; designs with multiple waves are sometimes referred to as *time series*.

The execution of longitudinal studies involves obstacles that stem from their length. Maintenance problems exist from the planning stage onward, including funding that is seldom secured for long projects and lasting participant collaboration that cannot be guaranteed beforehand. Once a study is launched, research difficulties are essentially the same as in any test-retest design, but they are amplified with time, as explained in the classic discussion of threats to validity by Campbell and Stanley (1963) that continues to be relevant across research methods. The extent to which a threat materializes depends on the particular design features, for example, interferences between successive tests increase with testing frequency, likewise, interviews in a case study with intensive researcher-participant interactions may turn into an intervention. A most bothering issue is attrition of the entry sample which is usually selective and leads to loss of comparability both within a given cohort and between initially comparable cohorts. Thus, for example, programs intended to enhance equality may seem effective just because students with lower motivation and academic achievements are more likely to be missing from follow-up waves as a result of higher rates of absenteeism, dropout, or school mobility. Despite attrition, internally valid conclusions and insights can be drawn through analysis of longitudinally matched data that attend only to participants with full data sets. Securing internal validity is crucial and overrides the risk of reduced ability to generalize. Longitudinal matching requires meticulous management of ever-growing data, which can be voluminous in qualitative studies. Storage of records is also necessary to keep options for future secondary analysis or follow-up of a seemingly completed study.



Longitudinal Studies in Science Education, Fig. 1 Research designs for hypothetical studies launched in 2015 to investigate changes over time during the grade 8–12 interval (cohorts are defined by calendar year at grade 8; years in the cohort/grade plane are periods of data collection, with retrospective data during parenthesized years)

Complementary Research Designs

Direct investigations over time with valid conclusions at both group and individual levels are possible only through true longitudinal designs. Other research designs that attend to the time dimension without actually following the same subjects can play valuable complementary roles, yet none can replace the gold standard. Figure 1 illustrates frames of hypothetical studies starting in 2015: a 5-year true longitudinal investigation of schooling from grade 8 to 12, along with complementary designs.

In *trend research designs*, data are collected from representative samples of the same population at different times. They conform to the working definition of longitudinal studies if the requirement for “same entity” is viewed broadly and includes samples drawn by the same procedures. In Fig. 1, a trend design is illustrated by the vertical sequence that encompasses grade 10 cohorts from 2015 to 2019. If the same sampling and data collection procedures are employed in the same schools, inter-cohort comparisons may reveal trends due to educational changes, demographic shifts, or historical events interacting with the results. Such trends should be considered in the interpretation of the grade 8–12 longitudinal study.

In *retrospective research designs*, data are collected at one point in time, on the same subjects, on previous periods, based on archives and human memory. In Fig. 1, the upper horizontal sequence illustrates data collection in 2015 from grade 12 backward. If the necessary data are student grades or other records from official files, then there is no difference between data collected retrospectively or in real time. Differences exist when studies concerned with meanings and processes attempt to reconstruct the past through student and teacher reports and reminiscences. Such data can be valuable, though limited in scope and reliability compared with real-time studies. In some cases a retrospective design is the only option, for example, in studies of teacher life cycles, narratives are the only source for tracing back early roots of knowledge, beliefs, or decisions to embark on a teaching career.

Cross-sectional designs do not accommodate the consensual sine qua non of longitudinal designs, since inferences on change over time are based on comparisons between data collected at the same time from different subjects across chronological stages. They provide no data on change at the individual level, and the validity of interpretations at the group level is limited by the incomparability of their different cohorts.

In the study illustrated by the diagonal sequence in Fig. 1, results of 12 graders who were 8 graders in 2011 may be inflated because they do not include students who dropped out since 2011; they may also be affected by educational interventions and events that would not happen to 8 graders from 2015 to 2019. The obvious advantage of cross-sectional over longitudinal studies is the provision of fast approximations on the long term.

Mixing of longitudinal and complementary designs has the potential to enhance investigations over time, provided that comparability is checked among the different elements. Intertwinement of retrospective data collections within longitudinal sequences can fill gaps between waves. A longitudinal study can be extended through patching of other study sequences, thus providing estimations of continuity and change over longer periods. Cross-sequential comparisons enable elucidation of trends, as has been done in large-scale cross-sectional and long-term longitudinal studies conducted periodically with nationally representative samples in the USA (e.g., Ingels et al. 2012).

Persisting Issues in Longitudinal Studies in Science Education

Publications that focus on longitudinal studies in science education include one comprehensive review (Arzi 1988) and two special journal issues with exemplary studies that provide important insights on long-term processes and outcomes and on how they were investigated (Shapiro 2004; Tytler et al. 2005). Overall, the literature does not include many research reports, and a close scrutiny reveals that the labeling of studies as “longitudinal” is sometimes permissive. Too often articles do not provide sufficient information on the research design, including actual collection and analysis of comparable data over time, which eventuates in questionable validity of inferences on the long term. Since difficulties are encountered in any longitudinal study, methodological transparency is necessary both to support conclusions and to guide further research.

The range of longitudinal research designs in the science education literature is wide, extending from descriptive case studies and follow-ups of school-based programs all the way to large-scale quantitative surveys employing sophisticated statistics and enabling further use of their databases. Longitudinal investigations can be found across areas in science education; however, since their number is limited, the thematic coverage is thin. Consequently, for example, when the notion of learning progressions emerged, again in the first decade of the twenty-first century, the existing longitudinal knowledge base was insufficient for grounding topic-specific hypotheses on extended periods. Researchers therefore turned to cross-sectional studies for quick answers, while acknowledging the necessity for elaboration and validation via longitudinal studies.

Across subjects in science education, longitudinal studies have unfolded complex long-term processes. In concept learning, for example, findings show that immediate instructional outcomes can erode, persist, or grow over time, initially undetected outcomes may appear later, and there are different patterns of individual student trajectories. Similarly, teacher learning and professional development are career-long processes with individual twists and turns that are impossible to predict from studies of beginning teachers. In reforms, too, changes take time to occur and it takes time to understand them, as promising results may fade away, but even if so, significant cumulative effects may be found years later. A single year – the required minimum in the working definition adopted in this entry – is often not enough, and an early closure of a study involves a risk of premature conclusions.

Each subject in the above examples has unique features that have been only partially explored longitudinally, or not at all, as is the case across areas in science education. The ever-existing calls for more longitudinal studies reflect their modest number and gaps between acknowledgment of importance and commitment to research which is not easy to conduct. Apparently, pressure to publish frequently and human nature to prefer short- over long-term tasks also affect the reluctance of researchers to embark on long-term adventures. The knowledge that has accumulated in science education through longitudinal studies is evidence that they are feasible and worth the effort.

Cross-References

- ▶ Assessment Framework
- ▶ Attitudes to Science and to Learning Science
- ▶ Ausubelian Theory of Learning
- ▶ Curriculum Evaluation
- ▶ Learning Progressions

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Meaningful Learning

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Keywords

Conceptual understanding

The term "meaningful learning" became prominent in science education through the work of the educational psychologist David Ausubel and his use of this label in the 1960s to designate learning that is in total contrast to rote learning. At its core this usage can be characterized as suggesting that, in most contexts most of the time, "rote learning is bad; meaningful learning is good." Such usage has become widespread, so that "meaningful learning" serves as a label for learning seen to be of worth, of real purpose, in a wide variety of contexts. These range from academic discussions of alternative conceptions and the need to pursue conceptual change to popular debates of educational fads (e.g., "does [some specific fad] actually lead to any meaningful learning?"). Meaningful learning has also been central in other theories of learning that have been variously influential in science education, including Wittrock's Theory of Generative Learning.

Cross-References

- ▶ Ausubelian Theory of Learning
- ▶ Conceptual Change in Learning

Mechanisms

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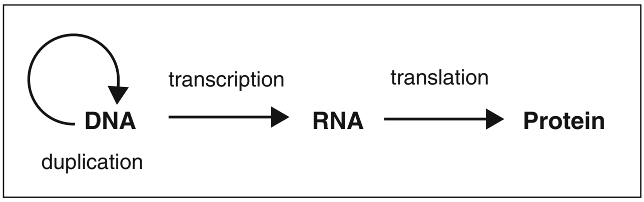
Keywords

Cognitive science; Explanations; Learning progressions; Models

A common and successful strategy for explaining something scientifically is to describe the mechanism that produces it. Mechanisms are composed of entities and activities that are, in various senses, in the world. Entities are things that behave or engage in activities. Activities are ways of working that produce phenomena. Succinctly put, "mechanisms are entities and activities organized such that they are productive of regular changes from start or set-up to finish or termination conditions" (Machamer et al. 2000,

R. Gunstone (ed.), *Encyclopedia of Science Education*, DOI 10.1007/978-94-007-2150-0,



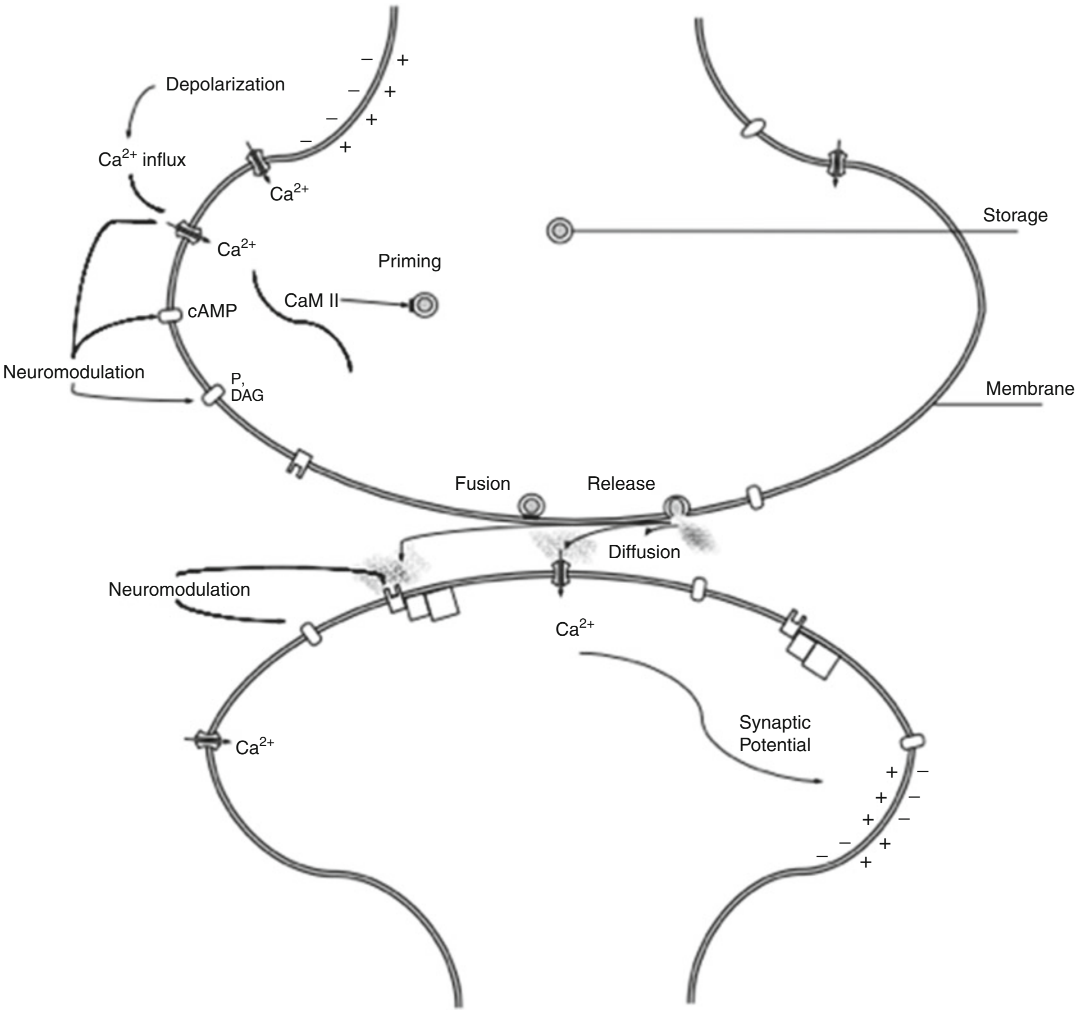
Mechanisms, Fig. 1 The central dogma of molecular biology (Redrawn, based on Machamer et al. 2000)

p. 3). Mechanistic explanations are representations (often verbal descriptions) of mechanisms.

Mechanisms may be described in varying detail. Mechanisms can never be completely described, since, given any context, there will always be more to be said about what is involved in producing a given phenomenon. Since no system is ever completely causally closed, there will always be additional entities or activities warranting inclusion. Nevertheless, we may distinguish mechanistic explanations from mechanism schemas and from mechanism sketches. A sketch is an incomplete description of a mechanism that contains many gaps or "black boxes" that cannot be filled in because of limitations in scientific knowledge; sketches are often apparent in ongoing scientific research. A schema is an incomplete description of a mechanism that contains many lacunae but where some gaps may be filled in with further details given current scientific knowledge. For example, Francis Crick's central dogma of molecular biology provides a schema for a mechanistic explanation of the uni-directionality of information transfer in biological systems (Fig. 1). A mechanistic explanation is a sufficiently filled out schema, such that our scientific knowledge fills in the gaps in a way that suffices for the explanatory needs of a field at a time and the interests of the investigators.

Let us consider some examples of mechanistic explanations, first, an internal combustion engine: a car moves because a high-energy fuel is mixed with air and burned in a special compartment so that energy is released to move a piston, which in turn moves a rod connected to other components that turn the wheels that propel a car by exerting force on the ground. We explain how a car works by providing a mechanism schema of how a drive system converts gasoline into rotational and translational motion. Yet another type of mechanistic explanation involving cars could look at the mechanisms established by legal and enforcement institutions that attempt to ensure that drivers stop at red lights, obey stop signs, put on the brakes, etc. Or, one might describe the macroeconomic relationships between gross domestic product, trade deficits, and supplies of and demands for various goods and services to provide a mechanistic description of the distribution of American-made automobiles in certain regions of the United States. To explain by describing the entities and activities that give rise to target phenomena is to explain mechanistically.

Consider, also, chemical transmission at neuronal synapses (see Craver 2009). Neurons are described as "firing together"; they propagate electrical signals from one to another as a group, in a complex, orchestrated, and poorly understood fashion that serves as the basis of the mind and nervous system. A neuron is a cell. Between each neuron lies a space called a synapse. When one neuron is stimulated, it propagates an electrical current along the length of its body. At the end point it reaches a synapse, which must be bridged to communicate with an adjacent neuron. Chemical transmission is the mechanism whereby the electrical signal from a neuron is converted into a chemical signal across a synapse (Fig. 2; cf. Machamer et al. 2000, p. 9). This neurotransmitter signal is then converted back into an electrical signal in an adjacent neuron. A textbook account of this is complex. It includes entities such as membranes, molecules, receptors, and transmitters, as well as



Mechanisms, Fig. 2 A diagrammatic summary of some entities and activities involved in synaptic transmission

activities such as depolarization, priming, fusion, and release. An explanation of how chemical transmission occurs begins with a description of which entities undergo these activities and how their doing so causes other entities to behave. Thus, the entire system is explained by showing how it proceeds from an initial condition to a later condition, resulting in communication between neurons.

In the history of the life sciences, the topic of mechanistic explanation has often been contentious, as some authors have argued there is something irreducibly special about biological systems that cannot be fully captured by them (e.g., Haldane 1913). Contemporary discussions of mechanism need not be committed to reductionism or to the claim that all mechanisms are specified at a lower level than the phenomenon being explained. For example, individual behavior at a biological or person level may be mechanistically explained by detailing an ecological, social, or cultural mechanism. So mechanisms for vision may be described, for example, in terms of chemical reactions, in terms of neuron connections, in terms of areas of the visual system, in terms of a person's cognitive capacities, and in terms of ecological and social dimensions. Thus, many mechanisms are explanatorily pluralistic.

A current trend in science education is to focus on scientific models as loci for instruction and learning (Gobert and Buckley 2000). Mechanistic explanations encompass such representations as diagrams, equations, and written description. Thus, mechanism sketches and schemata are well suited for this model-based paradigm. As the cognitive science of learning progresses, thinking about mechanisms will be central for thinking about teaching science. Just as we may describe mechanisms when giving scientific explanations, both teaching and learning may also be described mechanistically.

Cross-References

- ▶ Epistemology
- ▶ Learning Progressions
- ▶ Models
- ▶ Science Studies

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Mediation of Learning

▶ Socio-Cultural Perspectives and Characteristics
▶ Socio-Cultural Perspectives on Learning Science

Memory and Science Learning

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Keywords

Cognition; Computational; Information processing; Models; Neurophysiological

Introduction

Human memory can be thought of as the capacity for retaining and recalling experience. This retention can vary from a matter of milliseconds to a lifetime, and similarly the nature of recall can vary greatly. I will qualify the discussion here to specifically consider events for which attention plays a role and where the individual has the opportunity to control aspects of their cognition for tasks such as learning.

The second half of the twentieth century gave rise to modern theories of cognition and memory, many of which paralleled the emergence of computing technologies and the broad conceptual framework of information processing. The current accepted psychological models of memory trace their roots to early work by Broadbent and later by Treisman, Atkinson and Shiffrin, Neisser, Cowan, and Baddeley in the 1960s through 1980s.

Information Processing Models of Memory

Information processing models represent mental activity as occurring in a series of stages, with starting points and feedback loops at numerous points. These models typically encompass not only memory but also those processes that bracket memory functions within a learning task context. Common across most of these models is agreement on what stages of activity take place and the belief that different stages will require differing amounts of mental resources This common model starts with sensory processing, where raw signals in the environment gain access to the brain through the peripheral sensory organs (e.g., the eyes and ears) and are received and stored in a short-term sensory store. Information in these stores might reside for one half to 4 s before decaying. Only if information is selected by attentional resources is it then interpreted through a stage of perception. Perceptual processing itself generally requires few attentional resources (i.e., is considered automatic) and driven by both ongoing sensory input (termed "bottom-up processing") and inputs from long-term memory ("top-down processing"). This speed and relative automaticity is what distinguishes perception from cognitive processes. Attentional resources may select some perceptual information for more effortful processing by cognitive functions involving working memory.

Working memory, as defined by Baddeley, consists of three core components: the verbal-phonetic subsystem, the spatial subsystem, and central executive. The verbal-phonetic subsystem itself is composed of two components: the phonological loop that represents linguistic information and the articulatory loop where words or sounds can be rehearsed. The spatial component can be thought of as a visuospatial sketchpad which represents visual information in an analog form. The verbal-phonetic and visuospatial subsystems of working memory seem to function more cooperatively than competitively when it comes to allocation of attentional resources. That is, research has demonstrated that the limited capacity of working memory can be optimized by a division of incoming information between these two encoding channels. On the other hand, the limited capacity overall of working memory means that high demands on either of these two channels will result in interference and competition between information chunks and the inability to appropriately encode, manipulate, or transfer it to long-term memory. Some research has also suggested that this model of working memory should be amended to include a kinesthetic subsystem.

Long-term memory is organizationally different, with information either stored as declarative or procedural information. Models of knowledge representation are used to better understand how long-term memory procedural information (how to do things) may interact with declarative (factual) information or episodic memory (of specific events). Physiologically, procedural knowledge primarily occurs in brain systems involving the neostriatum (a subcortical part of the forebrain, the location of essentially all cognitive and perceptual activity) while declarative knowledge primarily involves the hippocampus (also in the forebrain). Various knowledge elicitation techniques can be used to build models of an individual's knowledge structures in order to better understand what it means to be expert at a domain or how one's knowledge structures change as they learn. The term mental model or schema can be used to describe an individual's cognitive structure with regard to a concept or system. Current work on learning trajectories or progressions is used to more fully describe how these cognitive structures manifest themselves as behaviors in learning contexts. It is important to remember that while long-term memory is considered both unlimited and permanent (baring injury or disease), it does not guarantee that an individual will be able to access this information when needed for a learning task. The context in which you are attempting to recall information, the cues provided for you, and the temporal and capacity challenges put on working memory will all influence your ability to recall information in a form that is most useful.

The overarching central executive serves a number of key functions, including (1) controlling the allocation of attentional resources to incoming stimuli, (2) coordinating multiple tasks and channels of information, and (3) retrieving and temporarily holding information from long-term memory. The dorsolateral prefrontal cortex is thought to play a key role in executive-attentional functions and, by extension, working memory functionality. Because of this close connection, individual differences are best explored through a combined system of working memory subsystems and executive-attentional control.

It is not surprising that there are also likely connections between working memory capacity, executive-attentional control, and general fluid intelligence. Because many of these operations require mental resources, the attention system helps direct and allocate resources based on both automatic and conscious action. However, it is important to remember that this resource is not binary and can be divided between multiple resources. Exactly how much and under what conditions continues to be an active area of research. It follows that the mind is not simply a passive recorder of incoming streams of data, but use of the working and long-term memory systems is a dynamic process that often involves conscious cognitively effortful activity. Learning and experience both recruit and alter brain structure as memory is utilized.

Understanding the role of memory in learning requires understanding the different affordances and constraints of working and long-term memory. In this information processing model, learning is considered to involve the ways in which long-term memory has been activated and shaped, via sensory and working memory systems. Individuals will chose to execute a response (or not) based on perception and shaped by working and long-term memory. Feedback they then receive via their sensory system will help direct further activity. Working memory, true to its name, is the crucible where the examining, comparing, evaluating, and transforming representations of information take place. Information received and created here will only be available later in time if it is placed in long-term memory. The usefulness of this information stored in long-term memory depends on whether the correct information can be recalled in the appropriate context and applied to the current task taking place in working memory. Central to this model of cognition is that working memory capacity is limited while long-term memory is not and that cognitive processes are much slower and reflective than automatic, perceptual ones.

The capacity limits of working memory interact with the transitory nature of this information. Not surprisingly, the more information one attempts to hold in working memory, the faster this information is likely to decay due to less resources devoted to its rehearsal and preservation. Conversely, more information can be more effectively held for longer periods of time in working memory if adjacent units are grouped, or chunked, together by associations in an individual's long-term memory. How information is presented can either facilitate or hinder an individual's ability to group and associate information in long-term memory. However, incorrect or inappropriate (for the learning task) information learned at a previous time and retrieved from long-term memory for this current learning task can interfere with the current working memory operations.

Other Models

Early theorizing on the nature of human thought and the emergent computer revolution led to connectionist models of cognition, broadly inspired by the physiology of the brain (i.e., neural networks). Two important computational models of cognition to emerge in the 1990s that combined connectionist with symbolic (rule-based) architectures were Anderson's ACT-R model and Newell's Soar model. Computational cognitive models such as ACT-R have been the basis for a new generation of intelligent tutors being developed to assist learners though dynamic, adaptive computer-based learning environments. Newer models based on Bayesian mathematical models do not attempt to mimic physiological structure but rather behaviors observed in humans and other animals. Bayesian probabilistic methods look at how prior knowledge can form alternative structures and make inferences as to the best representation to use given the available data and context. All types of computational models can be used to understand human cognition, predict human performance in learning tasks, and build computer-based tools that assist human learning.

There has also been a long-standing interest in understanding memory and attention by directly examining the neurophysiological functioning of animals and humans. Physiologically, memory is neither a single entity nor a phenomenon that happens in a single area of the brain. Historically, the invasive techniques required for these types of studies have limited the depth of probing into human physiology. Hence, researchers have used animal models where more invasive techniques were considered acceptable, or humans already suffering from neurological injury or disease. Recent breakthroughs in imaging (fMRI and PET) and other technologies have meant that neurophysiological research and refinement of theoretical models have made considerable strides in recent years. It should be noted that theoretical models based on physiological studies of neuronal networks should be differentiated from connectionist models developed around and modeled in computer systems, as the latter are only broadly based on the functioning of the human brain. Both these forms of model are valuable since both human and machine cognition are utilized in modern educational systems.

Memory in Science Learning

A learning environment that leverages what is known about memory and attention will recognize that learners come with memory that is structured differently and with varying degrees of expertise in different conceptual domains and in ways of processing information. Such an environment will attempt to maximize learner opportunities to effectively acquire new information that shapes these memory structures and to access and utilize prior memory structures. To that end, science learning environments guided by both human and machine teachers should assess prior knowledge (memory structures) and how students are able to utilize it.

Expertise in science can be used to describe both what information is contained within long-term memory and how it is organized and utilized to chunk or organize information in working memory. Experts will have a performance advantage in their areas of expertise in terms of how efficiently and effectively they can both process information and utilize it. Novices are distinguished from experts in terms of their lack of appropriate organizational structure of information in long-term memory.

Learning in science often involves inquiry cycles that involve the introduction of background conceptual material, investigation into scientific phenomena, and then reflection on the linkage of what was investigated to the broader scientific concept. Background conceptual material needs to link new material – often presented in textual, symbolic, and visual forms – with prior memory structures. Sweller’s cognitive load theory and Mayer’s associated multimedia learning theory leverage knowledge of working memory capabilities with learning contexts such as this to provide insight into how to design multimedia content for learning. Sound pedagogical strategies will encourage rehearsal and encoding to form strong linkages with existing long-term memory structures. Similarly, well-designed investigations will also provide information through multiple modalities and facilitate linkage to prior memory structures, providing scaffolded support to guide attention to the most salient information and support its rehearsal and encoding. Finally, reflective activities allow the development of long-term memory structures that can be generalized and used in related scientific practice with similar conceptual and procedural elements.

Science education is impacted by many of the same trends in technology infusion as other educational areas. Because of this, scientific phenomena are often experienced by students virtually mediated by computer-based environments. This trend has a number of characteristics that are impacted by human attention and memory. Computer interface design needs to be mindful of the bandwidth and temporal rate of information delivery so as to not to overload working memory. However, well-designed systems can leverage the fact that information can be distributed between computer and human memory and scaffolded in ways that support learning and retrieval. Similarly, emerging technologies around intelligent tutoring systems can create parallel models of student cognition to be used to help provide guidance and support for learning. Emerging understanding of the critical role the affective state plays in attention and effective, conscious cognitive effort also has led to a better understanding as to how learning environments need to be designed to both monitor and attend to the affective and cognitive dimensions of science learners.

Cross-References

- ▶ Information Processing and the Learning of Science
- ▶ Learning Progressions
- ▶ Multimodal Representations and Science Learning
- ▶ Neuroscience and Learning
- ▶ Prior Knowledge

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Metacognition and Science Learning

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Metacognition refers to an individual's knowledge, control/regulation, and awareness/monitoring of his/her thinking and learning processes. A more simplistic and less useful definition often used is that metacognition is thinking about one's own thinking. Research and scholarship in metacognition in science education typically draws on metacognition theory from educational psychology and engages and adapts that theory to address issues regarding the learning and teaching of science. Metacognition is executive, higher-order thinking that is superordinate to but that also interacts closely with the cognitive processes that students employ to construct knowledge and develop understanding via their science learning experiences. Successful science learners are consistently found to be adaptively metacognitive for the demands of their learning environments. While it might be appealing to view an individual's metacognition as good or bad, this is a simplistic notion. Rather, what might be valuable metacognition in one context or culture may be considered less or more valuable or adaptive in another, depending on the task or learning and cognitive demands of that particular context or culture. It is important to consider contextual and cultural factors when theorizing and investigating metacognition.

Developing and enhancing metacognition is congruent with existing and reform directions in science education such as conceptual change, scientific inquiry, and the use of information technology. Each of these reform directions has both commonly shared and reform-specific cognitive processes associated with them, and students should develop metacognition in relation to such cognition. For example, students should be metacognitive regarding the process of consciously considering new information against their existing scientific conceptions and theories and should be able to engage in conscious revision of their existing views in light of new information that might become available via the use of, for example, a microworld computer simulation. Further extending this example, students should be metacognitive regarding how the use of the computer technology might facilitate their learning and conceptual revision compared with, for example, the use of a textbook or a laboratory investigation. It is increasingly acknowledged that while domain-general metacognition across curricular subject areas is important, metacognition research and scholarship in the field of science education should and increasingly does account for the domain-specific science information to be learned by students and also the cognitive processes and metacognition to be employed by them to learn, understand, and employ that information and those processes within and beyond their science classrooms.

Metacognitive knowledge can be classified as declarative, e.g., definitions and/or conceptions of thinking and learning; procedural, e.g., knowing how to engage in learning and/or cognitive processes; and conditional, knowing when and why to engage particular learning and/or cognitive processes to achieve learning objectives. Science learners are all metacognitive to varying extents, but because metacognition is internal, it can be difficult to qualify and/or quantify an individual's metacognition. Much of students' metacognitive knowledge is tacit, and they often do not have a language to detail or explain their metacognitive knowledge or thought processes. This can lead to difficulty in evaluating the nature of students' metacognition and/or the impact of interventions aimed at developing and enhancing students' metacognition. It can also lead to difficulty in teaching students to be more and differently metacognitive and to be attentive and responsive to the varying demands of learning tasks and/or learning environments. Such a language of thinking needs to be taught to students and teachers.

Despite the importance of metacognition for science learning, science classroom learning environments are most often not sufficiently metacognitively oriented. The metacognitive orientation of a science classroom environment refers to the extent to which specific psychosocial factors known to assist in the development and enhancement of metacognition are evident in that environment. Improving the metacognitive orientation of a classroom environment requires that teachers make metacognitive demands on students to consider their thinking and learning processes, not just the science they are asked to learn. It also requires that students are encouraged and supported to talk with the teacher and each other about their science thinking and learning processes, that they are able to voice their views regarding the nature of the learning activities they are asked to engage in, and that they are increasingly given control over the selection and enactment of their preferred learning activities under the supervision of the teacher. Developing and enhancing student metacognition in science learning environments requires that teachers are themselves aware and knowledgeable of the thinking and learning processes required to learn and understand science in those environments. It also requires that teachers are able to incorporate the explicit teaching of metacognitive knowledge and related cognitive and learning strategies and the modeling of those strategies into their teaching settings and pedagogies.

Interventions aimed at enhancing metacognition seek to elicit metacognitive experiences in students. Metacognitive experiences are those conscious experiences that are educed in students when they reflect on and consider their thinking and learning processes, most often with reference to their learning and/or cognitive performance. They constitute key stimuli for students' revision of their metacognitive knowledge and dispositions. Interventions typically fall into one of two broad categories. The most common category of interventions involves engaging students in the use of metacognitive activities such as concept maps, Venn diagrams, and Predict-Observe-Explain (POE) or using metacognitive prompts to orient their cognition when they engage with science learning. The expectation or assumption is that students will often without prompting reflect on the use of those strategies and develop metacognition in relation to their use. The other, less common category of interventions involves explicitly inducing metacognitive conflict in students. Metacognitive conflict is analogous to cognitive conflict; however, it refers to the conflict experienced by students when they are asked to consider conceptions of learning, what it means to know and understand science, and how to know and understand science that run counter to their existing conceptions or beliefs regarding such matters. Metacognitive conflict approaches require that teachers are able to articulate increasingly sophisticated views of science and science learning to students that reflect the nature of science and science subject area disciplines. Ideally, a combination of interventions drawn from both categories would be evident in science classrooms so that students would be challenged to consider multiple means of constructing their understanding of science, what it learns to understand science, and how they can better learn and understand science. A primary goal of developing students' metacognition is to assist them to become independent, effective science learners who are able to tailor their thinking and learning processes to the demands of the science material to be learned and who can do so beyond their high school years.

Debate is ongoing regarding how students' metacognition can and should be investigated and evaluated. Two categories of methods in metacognition research are identified: online and off-line. Online methods are those employed when an individual is engaged in real time in a learning or cognitive activity. Such methods include think-aloud protocols and eye tracking. Off-line methods are those employed before or after task performance. They are typically self-report measures and include surveys, questionnaires, and interviews. Both online and off-line methods have affordances and constraints, and a researcher's selection and use of methods is guided by their epistemological assumptions, and the degree of inference they consider is appropriate in metacognition research. Online measures while targeting real-time cognition and metacognition might interfere with individuals' normal engagement in and performance of a learning task. Conversely, off-line measures while not interfering with students' real-time task engagement, cognition, and metacognitive activity are influenced by what students are aware of and/or can recall regarding their thinking and metacognition and the extent to which they can accurately report their thoughts. It may be that a combination of online and off-line methods could be employed in research studies to gain a comprehensive understanding of students' metacognition from a variety of perspectives. Further exploration of this possibility is necessary.

Priorities for future research on metacognition in science education include conceptualizing and implementing interventions to enhance students' metacognition and science learning in authentic, content-rich settings, investigations into teacher metacognition, and exploration of methods for seeking data leading to findings that can inform enhancements in science teacher pedagogy.

Cross-References

- ▶ Classroom Learning Environments
- ▶ Concept Maps: An Ausubelian Perspective
- ▶ Conceptual Change in Learning
- ▶ Culture and Science Learning
- ▶ Didactical Contract and the Teaching and Learning of Science
- ▶ Microworlds

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Metaphors for Learning

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Keywords

Acquisition metaphor; Participation metaphor

Metaphors for learning are metaphors that we use, either explicitly or in an only implicit manner, to describe learning. What often appears as but an innocent figure of speech may in fact inform how we think about the topic, what we are able to notice, and what pedagogical decisions we are likely to make. Different approaches to learning may have similar metaphorical underpinnings, and therefore it is useful to categorize them according to their underlying metaphors.

In this entry, a brief explanation on the role of metaphors in our conceptual thinking is followed by a succinct survey of the metaphors for learning identified by those who studied the topic. Two of these metaphors, known as *acquisition metaphor* and *participation metaphor* and considered as arguably the primary source of all known approaches to learning, are then presented in some detail.

Metaphors as a Source of Conceptual Systems

Metaphor can be defined as a familiar word or phrase used in an unfamiliar context. We are witnessing such metaphorical use while speaking about our ideas or thoughts as "crystallizing" and about love as "burning." In both these cases, a word – *burn*, *crystallize* – has been taken from its *source* domain, that of physical phenomena, and used within a *target* domain for which it was not originally intended, that of human thoughts or emotions.

Traditionally considered to be not much more than literary gimmick, the metaphor has been recognized in the last decades as the basic mechanism through which people cope with new situations and develop original ways of thinking. Nowadays, there is a consensus that any advanced human idea, be it everyday or scientific, grows from previous concepts through the mechanism of metaphor. The American linguist George Lakoff (1993) takes these claims to the extreme when he speaks about *conceptual metaphor*, the cognitive mechanism that transforms what one already knows – familiar conceptualizations, everyday bodily experiences, and forms of activity – into new ways of thinking. Whereas ubiquitous and usually quite helpful, this mechanism becomes truly indispensable when we face new phenomena. Indeed, it is only through the use of familiar words in a new context that we can make sense of unfamiliar situations. Similar claims about metaphors are being made these days by researchers who refuse to view human thinking as fundamentally different from any publicly accessible forms of activity and prefer to consider this inner process as a special case of communicating. Within this latter approach, metaphors are said to be generators of novel discourses. This formulation brings in full relief the systemic nature of metaphors, that is, the fact that metaphor-generated target discourses tend to reproduce considerable portions of source discourses.

Whether cognitivist or discursive, the assumption that metaphors are responsible for our conceptual systems leads to the conclusion that our bodily experience is the primary source of even the most abstract of our ideas. This fact has been explicitly acknowledged by philosophers of science, who point out, for example, that his familiarity with the solar system strongly influenced Rutherford's interpretations of his experimental data as indicating the structure he hypothesized for the atom. At the same time, claims are being made about risks resulting from the systemic nature of metaphors. Unaware of their being guided by unintended metaphorical entailments, the users may be led to unhelpful conclusions. To minimize the risks, we need to be explicit about metaphors underlying our thinking. In scientific research, and in studies on learning in particular, where it is crucially important to control our language for undesirable uses, identifying hidden metaphors is not just advisable – it is imperative.

Metaphors for Learning

The ways we tell stories about learning, whether in our daily life or in research, is full of terms and phrases that disclose the metaphorical origins of our talk. This is well illustrated by common learning-related expressions such as *construction* *of knowledge*, *mental scheme*, *internalization*, *scaffolding*, *apprenticeship*, *negotiating meaning*, and *appropriation*. Because these terms have no obvious "literal" counterparts, their metaphorical nature may not be immediately visible. On closer inspection, however, one realizes that the words *construction* and *scaffolding* originate in discourses on [house] building, the word *apprenticeship* is taken from discourse on vocational training, and the first associations that come to our mind upon hearing words such as *negotiating* or *appropriating* are human activities in domains such as politics or propriety management.

Two categories of metaphors are ubiquitous in research on learning: those that help us to think about different properties or types of learning and those that offer answers to the question of what learning is. In the above list of learning-related metaphorical terms, the first category is represented by the term *scaffolding*, which refers to the support granted to the learner by a more knowledgeable person; *apprenticeship* that speaks about learning that involves the learner's and teacher's co-participation in the activity to be learned; and *internalization*, Piaget's notion referring to a stage in learning where what has been done by physical manipulations can now be done "in the head" (Piaget, 1952). The second category, that of learning-defining metaphors, is represented here by the expression *construction of knowledge*, which many writers consider as an equivalent of the term *learning*. The constructivist metaphor is clearly an alternative to the one that portrays learning as a mere *transmission* of *knowledge*. Since defining metaphors constitute the foundation on which one's thinking about learning is based, each such trope combines with some other properties–describing metaphors better than with some others. Thus, for instance, constructivist metaphor is strongly associated with *mental schemes*, *internalization*, and *transfer*, whereas none of these expressions fits the participationist vocabulary.

Our metaphors for learning can make considerable difference in the ways we teach. The constructivist metaphor, first introduced to research on human development and learning many decades ago by the French psychologist Jean Piaget, has revolutionized Western pedagogy. Its long-term impact can be felt all around the world even today. It has been influential earlier and more widely in science than in any other area of the school curriculum. For some time before the advent of Piaget's innovative ideas, instruction had been shaped by the learning-as-transmission-of-knowledge metaphor, which is deeply engraved in many languages – consider, for instance, such English expressions as "getting education" or "imparting knowledge." This metaphor pictures the teacher as the "broadcaster" and the learner as the "receiver." This vision supported the lecture-based frontal teaching that had been the dominant form of school instruction all around the world until a few decades ago and can still be found in many places. Once educators began thinking about learning as the activity of building one's own knowledge, lecturing started giving way to more active and interactive pedagogies, guided by the principle of encouraging learners to voice and develop their own ideas. Another metaphor, this time more explicit, has been coined to describe the kind of change that occurred with the transition from the transmission to construction metaphor: the teacher, rather than being "the sage on the stage," was now playing the role of "guide on the side."

Acquisition and Participation Metaphors

In spite of the considerable diversity of figures of speech that pervade our talk and shape our thinking about learning, it is possible to divide all the resulting approaches into two broad categories. Thus, for instance, although the transmission and construction visions of learning are quite different in their assumptions and implications, they can still be seen as two instances of yet another, more fundamental metaphor: the metaphor of learning as an act of taking possession over some entities – concepts, knowledge, skills, or mental schemas. This *acquisition metaphor* comes to the scholarly discourse directly from everyday expressions, such as *acquiring* or *imparting knowledge*, *having concepts*, or *getting (seeing) meaning*. The alternative metaphor is the *participation metaphor*. This trope, which originates in the sociocultural ideas of Vygotsky and his followers (Vygotsky, 1978), pictures the Learner as the peripheral participant (Lave & Wenger, 1991) in the special forms of an activity that humans developed throughout history. School subjects, such as mathematics or science, are good examples of such activities.

These two metaphors for learning differ considerably in their most fundamental entailments and in particular in those that deal with the question of what it is that changes when people learn. Whereas the acquisition metaphor portrays learning as the process of extending and transforming mental entities, the participation metaphor equates learning with changes in patterned, recurring ways of acting. The former approach, therefore, assumes a basic ontological difference between what happens inside and outside the human head, whereas the latter approach makes this distinction between internal and external processes irrelevant. In other words, the acquisition metaphor is fundamentally dualistic, whereas with the participation metaphor, the duality disappears. This basic ontological disparity has been shown to entail many other differences, either in ways in which the resulting theories view and explain phenomena or in how they inform the practice of teaching and learning and associated values (Sfard 1998).

Since the participation metaphor does not easily combine with our everyday thinking and talking about learning, the first researchers who opted for this metaphor had to be strongly motivated to be able to abandon the time-honored acquisition metaphor. Indeed, they did have a valuable insight to gain. On the basis of the acquisition metaphor, it was difficult to account either for the cross-cultural and cross-situational diversity of individual learning or for the existence of societal learning. This latter type of learning, which is widely believed to be unique to humans, expresses itself in the increasing complexity of our ways of thinking and acting across successive generations. Acquisitionist researchers, for whom knowledge to be acquired comes directly from the world and is relatively independent of social interactions, did not have means to account for those changes that transcend a single life span. By reconceptualizing learning as a process of becoming capable of acting in uniquely human ways, the participationists provide a solution to the conundrum: An individual participant may offer her own version of an established activity, and if her innovation is deemed an improvement over the former way of doing things, it is likely to spread to the entire community. In this way, human activities are constantly refined, and the innovations are passed from one generation to the next. Once adopted by the community, the reformed ways of acting will be the ones to be learned by every new member. This participationist model of learning also explains why different communities are likely to act differently in the face of similar tasks.

The difference between the acquisitionist and the participationist versions of human development, therefore, manifests itself in how we understand the origins and the nature of human uniqueness. For the acquisitionist, this uniqueness lies in the biological makeup of the individual. The adherents of a participationist vision of learning, on the other hand, believe that it is the collective life that brings about all the other uniquely human characteristics, with the capacity for individualizing the collective – for individual reenactments of collective activities – being among the most important of these characteristics.

Once it is accepted that scientific theories are but metaphors turned into rigorously told stories, those who evaluate theories become more interested in the question of whether a theory is helpful than in the query of whether it is true. Debates between adherents of different metaphors, therefore, are not about facts – about what learning *really* is – but about which of the metaphorically grounded visions of learning answers more questions in a more convincing way. The response to this query may depend on what is being asked in research. Different metaphors for learning may thus coexist, serving different areas of research for different purposes.

Cross-References

- ▶ Communities of Practice
- ▶ Constructivism
- ▶ Didactical Contract and the Teaching and Learning of Science
- ▶ Language and Learning Science
- ▶ Pluralism
- ▶ Prior Knowledge
- ▶ Values and Learning Science

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Microworlds

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Keywords

Simulation; Virtual lab

The term microworld was first introduced by Seymour Papert as part of the pedagogical philosophy of constructionism. To Papert, a microworld is a "…subset[s] of reality or a constructed reality so … as to allow a human learner to exercise particular powerful ideas or intellectual skills" (Papert 1980, p. 204). In this definition, microworlds are very open-ended in pedagogical style. Typically, microworlds are models of scientific or social phenomena that represent the domain-specific properties and conceptual representations of the phenomena of interest, thereby providing perceptual affordances and conceptual levers to the learner.

The degree of structure used to guide students' activities in learning environments, particularly those involving microworlds, is a topic that has been debated in science education, where some have encouraged open-ended exploration by students (as does Papert), and others have offered guidance or structure within the microworld to promote optimized learning. In our environment, Inq-ITS, we use carefully constrained technology "widgets," embedded within a broader technology learning environment to support a degree of open-endedness while also including structured guidance so that students can hone their inquiry skills (Gobert et al. 2013). These widgets, together with the artifacts students generate, serve to represent and make salient the products and processes of inquiry for the learner to support both effective monitoring and meta-level understanding of inquiry. Using microworlds, students formulate hypotheses and test them, interpret their data, warrant their claims, and communicate their findings.

In our work, we instrumented our environment and microworlds to log all students' interactions, which support real-time analyses (i.e., of the log files) based on knowledge-engineering and educational data mining techniques. This results in assessment metrics for researchers and teachers on the specific inquiry skills of interest. It also helps us scaffold students' inquiry processes in "real time" (i.e., during the microworld session).

Cross-References

- ▶ Simulation Environments

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Milieu

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Keywords

Adidactical; Didactic contract; Didactic milieu; Epistemic system; Symbolic forms; Teaching

In this entry, we discuss the notion of milieu as interpreted by the French educational didactician Guy Brousseau (1997). We may generally define this concept in the following terms: the milieu is the actual material and symbolic structure of the problem at stake, which one has to deal with in order to solve this problem (Sensevy 2012). Here and hereafter, the term "problem" refers in a very general way to any situation in which one has to restore an equilibrium, in the Dewean sense (Dewey 1938).

Consider this example: at primary school, students are asked to reproduce a puzzle by enlarging it, in such a way that a segment which measures 4 cm on the model will measure 7 cm on the reproduction. The pieces of this puzzle constitute the milieu that the students face for this "enlargement problem." This kind of milieu responds to three conditions:

1. *The teacher's intentions are inscrutable*. Here, the students ignore the specific teacher's teaching intentions. They concentrate on a pragmatic purpose (enlarging the puzzle), and at first they do not recognize the kind of knowledge (proportional reasoning) necessary to enable them to solve the problem. In this way, the students have to achieve certain autonomy.
2. *The relationships within the milieu are pregnant and adequate*. In enacting their activity, the students get feedbacks from the milieu, which helps them to make decisions about the strategies they use. For example, as they have to enlarge the puzzle in such a way that a segment, which measures 4 cm on the model, will measure 7 cm on the reproduction, they may decide to add 3 cm to every dimension. As a result of this strategy, the pieces are not compatible; the students may realize concretely that the additive strategy is not a good one. The milieu feedbacks are pregnant in that they focus the students' attention on the relevance of the used strategy. They are adequate, in that an effective proportional strategy in making pieces will obtain their compatibility.
3. *The knowledge at stake provides a winning strategy in problem solving*. A specific knowledge (in the puzzle case, proportional reasoning) enables students to solve the problem. In this kind of milieu, the students can examine the situation, take a decision, enact it, and judge on their own the relevance of their strategy, according to the milieu feedbacks.

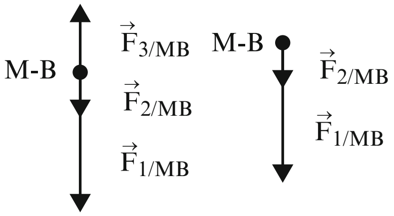
With respect to these three conditions (specially the first one), Brousseau (1997) draws attention to two fundamental features of such a milieu that he terms adidactical. First, it "lacks of any didactical intentions with regard to the students" (Brousseau 1997, p. 40). In our example, the signs provided by the pieces of the puzzle are non-intentional ones and opposed to the students' goal (enlarging the puzzle) until they use the proportional strategy. Second, designing an adidactical milieu means taking into account not only the specific knowledge this milieu has to embed but also the current knowledge system with which students will approach this milieu. This is the reason why Brousseau defined the milieu as "the system opposing the taught system or, rather, the previously taught system"

(Brousseau 1997, p. 57). In our example, students invariably act by adding 3 cm to every dimension. They face the adidactical milieu with an additive knowledge system, which provides them with their actual ineffective strategy.

Within this perspective, one may acknowledge the very nature of the teacher's work. In order to describe the teaching-learning relationship, one has to be able to call for another concept, that of didactical contract (Brousseau 1997; Sensevy 2012). The didactical contract organizes the actual system with which the students deal with the milieu. In our puzzle example, one could say that students cope with the milieu within an additive contract, which has stemmed from the previous teacher and students' joint action in mathematics. The didactical contract can be viewed both as a system of expectations between the students and the teacher and as the current students' strategic system.

One might think that the notion of milieu is specific to a certain kind of teaching-learning process. It is true in the sense that a milieu cannot be designed without taking into account the specific knowledge it embeds. But the notion of milieu has a general relevance, in that it refers to the actual material and symbolic structure of the problematic situation, insofar that this structure may provide feedbacks for the student's epistemic action. In this respect, let us consider an activity in the topic of mechanics (often taught in grade 11). This activity (Tiberghien et al. 2009; Sensevy et al. 2008) occurs while introducing the three laws of Newtonian mechanics. It aims at familiarizing students with the direction of the action and helps them to differentiate between action and motion. Then, the designers elaborate a milieu where directions of action and motion are different and observable even with common sense.

In this activity, the students have to throw and catch a medicine ball (heavy ball) and then answer a series of questions. The first one is "locate and note the moment(s) where you exert an action on the medicine ball; each time specify in which direction you exert this action on the medicine ball." For the students, it is not easy to differentiate direction of action and motion when they catch the medicine ball at its lower point, and some of them say they exert a force downward. After a while, the feedbacks of the milieu (the way their hands have "to resist" to the ball) may help them to begin to conceptualize the situation accurately. This milieu (medicine ball) has a lot in common with the previous one (puzzle). It provides some feedbacks that are more or less immediately perceived by the students (the puzzle pieces do not fit together; the hands exert a force upward). One could term these kinds of feedbacks causal feedbacks. But there are other feedback possibilities in a milieu.



Milieu, Fig. 1 Two kinds of proposals for approaching the "medicine ball" problem

Let us consider now another situation, in which the milieu is a rather complex one. After having worked on the medicine ball problem, the students have to study the whole movement of the medicine ball within a specific activity ("Aristotle or Galileo?"). The students have to analyze different students' answers to the task of "representing the forces which are exerted on the medicine ball (when it is going upward) represented by a point and noted M-B." They are asked to study two proposals (summarized in Fig. 1), composed by two annotated vectors and a text:

> One representation is correct from the point of view of the current model of mechanics (initiated by Galileo). The other representation corresponds to an intuitive analysis of the situation: according to this point of view (close to Aristotle's) there is always a force in direction of the movement.

In this problem, the students have (1) to identify which type of answer refers to an Aristotelian viewpoint, (2) to identify the systems 1 and 2 which act on the system M-B and to draw a conjecture about what the additional force represents for the students (A) and why they need to represent this force, and (3) to rely on the interaction model in order to justify the fact that this force does not model an action exerted by the medicine ball when it goes upward.

How is the milieu shaped in this situation? First, the students are confronted with a text from which they have to understand that the problem to be solved consists of analyzing two different student's responses. Second, they have to pay attention to the fact that the student's responses are vector representations. Third, while reading the text, students have to focus on a specific sentence ("according to this point of view (close to Aristotle's), there is always a force in the direction of the movement") in order to be able to work out the problem at stake. By referring to the previous sentence, they have to recognize this Aristotelian view as "incorrect." Fourth, they have to refer their analysis to the moment when the medicine ball is going up. Fifth, they have to scrutinize the two representations in order to identify which group analyzes the situation "intuitively," by drawing a force in the direction of the movement. Thus they have to consider the representation A and identify the vector F3/MB as expressing the Aristotelian viewpoint of a force in the direction of movement. They have to formulate hypotheses about the reason why the students need to represent this force. Finally, they have to justify the "fact that this force does not model an action exerted by the medicine ball when it goes upward," by applying the interaction model. According to the current didactic contract, students are supposed to recognize that there are only the earth and the air which exert an action on the ball and that both of these actions are downward.

If we compare this kind of milieu to the previous ones studied (e.g., the "feel the medicine ball" milieu), we can acknowledge deep commonalities and striking differences. In both ways the students have to decipher and take into account a set of symbolic forms (the medicine ball and the hands pressure, the different meanings in the text of the problem), which refers to the nature of the problem at stake. Then they have to inquire into this set of symbolic forms in order to institute logic relationships between them and to transform them in an epistemic system of symbolic forms. But there is also a conceptual difference between the two kinds of milieu. In the first milieu (the "feel the medicine ball" milieu), students have to experience causal feedbacks by interrogating their own body, which functions as a milieu. In the second milieu (the "Aristotle-Galileo" milieu), they have to experience rational feedbacks, by inferring new meanings from the semantic and semiotic units they put in relation.

But above these commonalities and these differences, there is a deep kinship between the two milieus. Even though the teacher's intentions can be used by the students for working out the problem, it is not possible for them to rely on this recognition to solve the problem. In order to solve it, they have to orient themselves in the milieu, then to inquire into the milieu and, in doing so, to encounter the fundamental meanings of the physics involved in this milieu. It is worth noting that the teacher's work is crucial to help the students achieve their inquiry. The art and the science of teaching could be seen as a way of monitoring the relationship between the student's work and the milieu.

Cross-References

- ▶ Agency and Knowledge
- ▶ Didactical Situation
- ▶ Epistemic Goals
- ▶ Transposition Didactique

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Mindfulness and Science Education

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Keywords

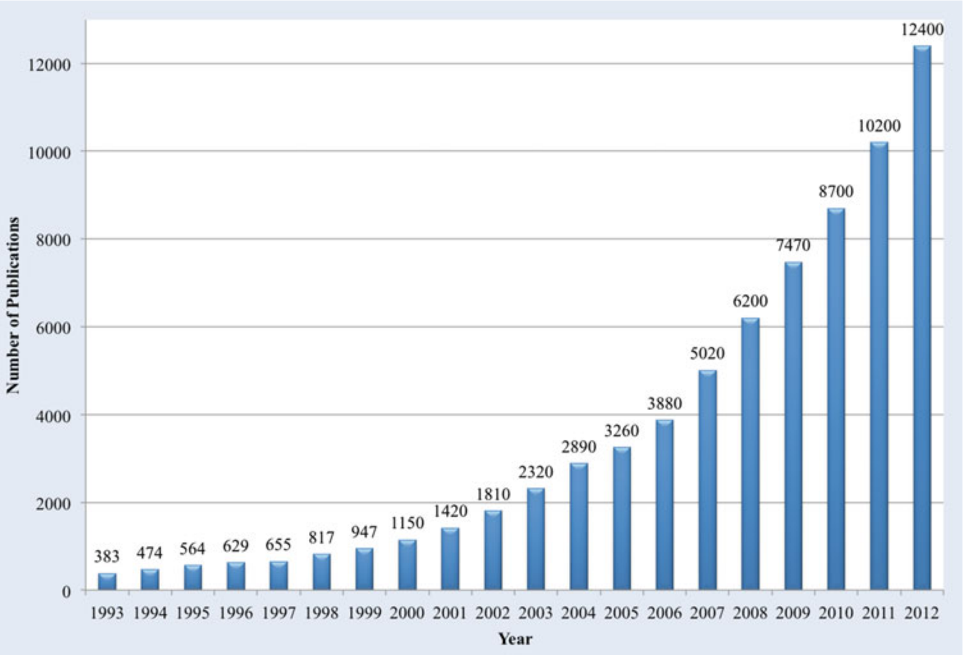
Heuristics; Interventions; Meditation; Mindfulness; Wellness

> . . . it is my fervent aspiration that our culture will pay more attention to well-being, will include strategies to promote well-being with our educational curricula and within the healthcare arena, and will include well-being within our definitions of health. These changes would help to promote greater harmony and well-being of the planet. (Davidson 2013)

In the above quote, Richard Davidson, a leading scholar and one of the pioneers of contemplative neuroscience, echoes the wishes of a growing number of like-minded enthusiasts who call for the expansion of the goals of the twenty-first century education to include promotion of wellness and sustainability. After decades of seemingly nonstop curriculum reform, much of which has focused on the production of scientists and increasing participation in science-related professions, it is desirable to revamp the goals of science education to address wellness and sustainability as well as goals that relate to the grand challenges faced by humanity. It is opportune to orient curricula to understanding the body and the mind and developing tools to afford lives as functionally literate citizens. Adapted from Buddhist traditions, mindfulness practices offer a unique opportunity to address in the classroom the cognitive and the oft-neglected affective dimensions of human ontology. As evidenced by the exponential growth of mindfulness-related publications (Fig. 1), there is widespread interest in the applicability and potential benefits of mindfulness in various fields of social life including educational contexts. This interest is fueled largely by the recent developments in the field of contemplative neuroscience that provide compelling evidence for our brain's enormous plasticity (ability to change its structure and function) and for the significance of the bidirectionality of the mind-body connection. Mindfulness training emerges as affording a number of positive changes in the brain which in turn improve the functioning of our bodies.

Mindfulness involves intentionally remembering to pay attention to the present moment experience – a disposition that defies our default preoccupation with analyzing and obsessing about the past or charting out and worrying about the future (so-called mind wandering). This present moment awareness is accompanied by a nonjudgmental acceptance of one's thoughts, feelings, and perceptions and seeing things for what they are without identifying with them. Such an accepting mindset can translate into increased levels of caring for the natural world. Mindfulness training has been linked to a range of cognitive, social, and psychological benefits to students and teachers. It supports development of self-regulatory skills associated with emotion and attention, self-representations, and prosocial dispositions such as empathy and compassion (MLERN 2012). Furthermore, mindfulness tends to decrease stress, depression, anxiety, and hostility. An increase in mindfulness may involve a higher incidence of focus, heightened awareness of thoughts and emotions and their relevance to learning, and awareness of what is happening in the moment.

Research for at least a half century has shown a relationship between emotions and cognitive focus. For example, studies indicate that positive emotions are associated with broadening of cognitive processes, and negative emotions are associated with narrowing of cognitive processes. There are numerous ways to interpret the research and associated theoretical frameworks in relation to the teaching and learning of science. However, it seems clear that the valence and intensity of emotion are salient. We conclude that it is important to be aware of the mediational potential of emotions. In terms of mindfulness, the goal is to be aware of emotions and endeavor to "let them



Mindfulness and Science Education, Fig. 1 Growth in the number of mindfulness-related publications over the last two decades. Data obtained from a search for “mindfulness” in Google Scholar

go,” making sure that they do not mediate participants’ conduct in ways that prove to be distracting and deleterious to learning. In the event that a participant decides that emotions are persisting and are adversely affecting learning, it is important to know how to intervene to sever attachments and/or reduce the intensity of the emotions.

Research on the intensity of emotions and focus has implications for teaching science. For example, consider a classroom incident reported by Tobin and Llena (2010). During a lesson on conversion of units, the teacher and several students were frustrated with most students’ performance on a recent quiz. The regular science teacher had been absent due to illness and a substitute had been teaching the class. Students were having difficulty following their substitute science teacher’s efforts to re-teach the work for which their test performance had been poor. An altercation broke out when a student leant across to clarify for another student what the teacher had said. The teacher reprimanded her for speaking while he was speaking. Almost immediately the learning environment became dysfunctional in many respects. The teacher’s anger was intense, represented through his gestures, prosody, and spoken text. Consistent with the intensity of emotion decreasing focus, the teacher was less able to attend to teaching the students about conversions from one unit to another. His oral presentation was slow, contained long pauses, and included utterances about “rude student.” Some students regarded the altercation as a performance and laughed at what was happening, regarding the text as unintelligible, an object for humor and ridicule. For the student who had been reprimanded, words such as “rude student” were inflammatory and catalyzed further outbursts, ratcheting up the intensity and distribution of high emotions.

In a very short time interval, less than a minute, the teacher endeavored to continue teaching, while at the same time he continued to refer to the student as rude and taunted her by mimicking her prosody and chanting “temp, temp, temper” as she reacted with high intensity, “you have every nerve to call me a rude student. . ..” At the same time laughter punctuated a turbulent classroom environment in which an increasing number of students’ actions were accusing and disrespectful and the teacher’s words were taunting and escalating. Laughter was polysemic, some instances possibly intended to encourage an escalation of the altercation, other instances reflecting amusement at what was happening, and nervous laughter that projected anticipation and acknowledgment that unfolding events were dangerous and cascading out of control. A key point of emphasis is that the learning environment was not mindful and the intensity of emotions focused actions away from the teaching and learning of science. Although there was widespread awareness of what was happening, there were no corrective interventions to reestablish a focus on learning science. In this context we regard it as a critical priority for science educators to use interventions, such as heuristics and breathing meditation, to create and maintain mindful learning environments.

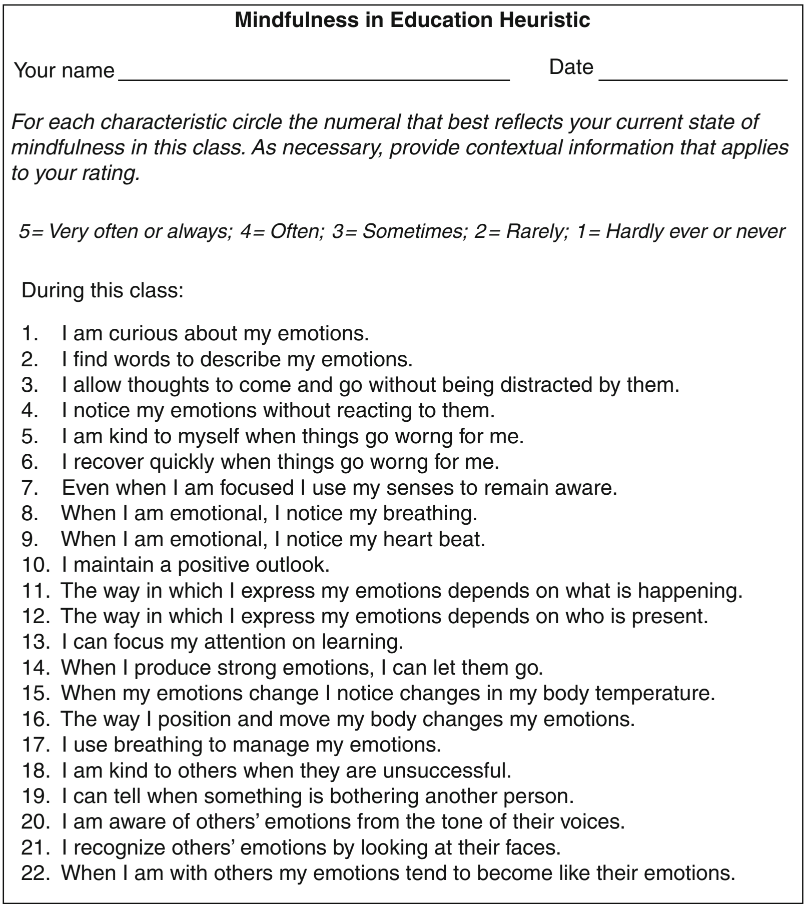
Lack of fluency in a classroom is often associated with high levels of emotional intensity and low levels of mindfulness. Of concern is the impact of sustained intense emotions on the well-being of teachers and students, a concern that is even greater in those contexts such as in the USA where there are well-documented trends associated with teacher turnover and student absenteeism. It is therefore imperative to understand and minimize undesirable negative emotions in the classroom and produce more positive emotional climates and more desirable states of wellness. The potential of mindfulness to address some of the intractable problems of education constitutes a strong rationale for the use of mindfulness-based interventions.

Cultivating Mindfulness in the Classroom: Mindfulness-Based Interventions

Over the last decade, a number of approaches to cultivating mindfulness in educational settings have been developed. Many of the programs are loose adaptations of the Mindfulness-Based Stress Reduction Program (MBSR) originally created for clinical purposes by Jon Kabat-Zinn. An alternative approach to incorporating mindfulness-based interventions into teaching and learning practices involves the use of heuristics (refer to Fig. 2 for an example of a heuristic). Consistent with the hermeneutic tradition, using a heuristic is a way of surrounding the construct with meaning through a series of statements (referred to as characteristics), each describing some aspect of mindfulness. As students or teachers read each characteristic, they select a point on the available rating scale. This process is meant to afford getting insights into one’s conduct vis-à-vis various dimensions of mindfulness. The theory that supports this intervention is reflexive inquiry (Bourdieu and Wacquant 1992) where reflexivity may be understood as becoming aware of the unaware. Because so much of what happens in social life happens without conscious awareness, reflexivity is important for actors, such as science teachers and their students, so that they can identify aspects of their practice and their supporting rationale, changing them as desirable to benefit the collective (Tobin 2012). Accordingly the use of heuristics aims at deepening awareness of self and others and of the surrounding structures. As students and teachers ponder the characteristics of mindfulness, they become aware of them and may pay attention to conduct that reflects those characteristics within themselves and each other. As the participants’ awareness of mindfulness increases, they often indicate the desire to change their conduct to more closely reflect an idea expressed in a heuristic. Consequently, changes in their conduct may become visible. Such positive changes have potential to contribute to a more harmonious learning environment. For example, students and their teachers may develop more compassionate attitudes toward self and others and learn to replace reacting with responding which may be associated with decreased incidence of aggression and bullying.

A useful feature of a heuristic is its malleability. A heuristic may be adapted to fit any educational context: a science class at different grade levels, teacher training or professional development,

Mindfulness and Science Education,
Fig. 2 Mindfulness in Education heuristic



Mindfulness in Education Heuristic

Your name ________________________________ Date ________________

For each characteristic circle the numeral that best reflects your current state of mindfulness in this class. As necessary, provide contextual information that applies to your rating.

5= Very often or always; 4= Often; 3= Sometimes; 2= Rarely; 1= Hardly ever or never

During this class:

1. I am curious about my emotions.
2. I find words to describe my emotions.
3. I allow thoughts to come and go without being distracted by them.
4. I notice my emotions without reacting to them.
5. I am kind to myself when things go worng for me.
6. I recover quickly when things go worng for me.
7. Even when I am focused I use my senses to remain aware.
8. When I am emotional, I notice my breathing.
9. When I am emotional, I notice my heart beat.
10. I maintain a positive outlook.
11. The way in which I express my emotions depends on what is happening.
12. The way in which I express my emotions depends on who is present.
13. I can focus my attention on learning.
14. When I produce strong emotions, I can let them go.
15. When my emotions change I notice changes in my body temperature.
16. The way I position and move my body changes my emotions.
17. I use breathing to manage my emotions.
18. I am kind to others when they are unsuccessful.
19. I can tell when something is bothering another person.
20. I am aware of others' emotions from the tone of their voices.
21. I recognize others' emotions by looking at their faces.
22. When I am with others my emotions tend to become like their emotions.

a cogen session (see the entry Teacher Research), etc. It may change its format (i.e., become a narrative); characteristics may be added, deleted, or altered to adequately reflect salient features of a particular educational setting. Similarly a heuristic may or may not include a rating scale associated with each characteristic. If a rating scale is included, the scale points can be written to fit the context of use. A heuristic may be completed in "one sitting" or alternatively individual characteristics may be used each day to draw attention to different dimensions of mindfulness allowing students and teachers to make personal choices about each in meaningful ways. This could be done in a variety of ways including the use of technology, cell phones, blogs, chalkboards, etc. Heuristics may be used for planning and guiding classroom activities with the purpose of facilitating adoption of practices that are characterized by mindful attention, focus, and compassion to self and others.

Breathing meditation is often an integral part of mindfulness training. Focusing on the breath allows participants to bring their attention to the present moment. It also assists with disassociating oneself from any (especially negative) thoughts and emotions. Breathing meditation may be used at the beginning of a class session to help students and teachers calm their minds and sharpen attention and focus. Using breathing meditation in a science classroom may afford exploration of the relationship between emotional feelings and respiration (the mind | body connection) and its significance for emotion regulation. Accordingly, students and teachers may observe changes in their emotional states as they practice deep abdominal breathing. Conversely, their attention may be brought to the changes in their breathing patterns (and possibly other physiological markers such as fluctuating heart rate) as their emotional states shift. Increased awareness of these connections may be accomplished through the use of relevant characteristics in a heuristic or through other techniques such as the use of oximetry (see the entry Teacher Research). Breathing meditation may be presented as a medical intervention that is associated with improvements in one's well-being. Breathing meditation may be modeled and facilitated by the teacher or by students. It may be a relatively short activity lasting between 3 and 5 min at a time. Participants may be encouraged to maintain the practice outside the classroom if they find it beneficial.

Mindfulness in Science Education

Science process skills became a visible part of the science curriculum in the post-Sputnik reform movement associated with the 1960s and 1970s. Basically, curriculum developers considered the steps of the scientific method and/or problem-solving and broke them down into skills. Different projects had different lists of process skills, in part because materials were developed around different psychological theories of learning. Prominent among these were the learning theories of Jean Piaget and Robert Gagné. Consider the 5 Es (engagement, exploration, explanation, elaboration, and evaluation), a present-day articulation of the Learning Cycle, which was based on Piaget's developmental theory and emerged in the post-Sputnik era as a framework for the Science Curriculum Improvement Study in the USA. From a sociocultural point of view, each of the 5 Es is an interaction chain (Collins 2004), that is, involving multiple interactions between individuals and social artifacts that are enacted using available structures (i.e., resources).

The quality of enactment reflects criteria such as fluency (i.e., enactment occurs just in time, is anticipatory, and is appropriate) and the extent to which others' actions are in synchrony and maintain flow. It is essential for successful interaction chains to occur in order for students to enact any of the 5 Es effectively and appropriately. The likelihood of this happening can be heightened if students establish and maintain focus and fluency while being aware of (attentive to) unfolding events that are salient to their learning. If others are involved in an interaction, for example, it is important that an actor is aware of emotional styles related to the extent to which he/she or others are expressing emotional cues. Language is an important tool for enacting process skills when actions are internal (i.e., thought), external (i.e., spoken or written), and a combination of both internal and external.

For example, the quality of enactment of a process skill concerns the words and utterances used, their prosody (e.g., loudness, frequency modulation, intonation, etc.) and proxemics (e.g., gestures, body movement and orientation, eye gaze, head tilt, etc.). Quality counts. In addition, what counts as quality will reflect the theoretical frameworks that underpin central criteria such as teaching and learning. For example, in terms of the sociocultural framework that we [the authors] adopt in our research, dialogue is central. No matter what happens to be the focus of the curriculum, we want the enactment and associated interaction chains to be characterized by dialogic inquiry. That is, as teachers and students interact, we want them to be respectful to one another, share time of talk and the number of talking turns, listen attentively to what others have to say, make sense of it, and understand its affordances in comparison to alternatives. Also, if injustices arise we expect participants to speak out in favor of corrective action. When individuals speak, they do so for the benefit of others, not just for themselves.

When science process skills were initially emphasized in science education, there were clichés to the effect that "science is a verb," "science is something that is done," and "authentic science" – meaning that what children might do, as science, would likely differ significantly from what postdoctoral researchers would do as science. It was argued that science had a role in terms of enhancing functional literacy in an increasingly technological society in which citizens have the knowledge to feel at home with the technologies they use in their lifeworlds and are not intimidated by them. The process skills learned and employed in school science, it was argued, would be available for use in different fields of the lifeworld, including shopping, working, hobbies, and consuming media. Now, more than six decades later, there is a compelling argument that students should know about healthy lifestyles and bodies, including neuroplasticity. To know, in the sense we use it here, extends far beyond just knowing the facts to include enacting healthy lifestyles and engaging in activities that transform the structure and functioning of the brain. We offer mindfulness as the process skill of the present decade.

Sound Bodies and Sound Minds

The emerging science behind the benefits of mindfulness to wellness provides support for incorporating contemplative practices into the educational arena. Mindfulness-based interventions are associated with positive outcomes for students and teachers through addressing cognitive and affective dimensions of teaching and learning. Whereas mindfulness can be a constituent of a traditional approach to science education, we regard it as a central component of a radical transformation of science education to embrace overarching goals related to wellness and sustainability. Mindfulness is a way of enacting social life that can expand learning potential and ameliorate the nature and intensity of emotions that rise and fall in the normal course of life. As part of the toolkit that individuals possess, mindfulness heightens awareness of emotions and their attachment to the ongoing conduct of social life. Given the alarming increase of violence in institutions that previously have been regarded as sanctuaries, such as schools, we regard as a priority for all humans to learn about mindfulness and to enact it in the course of everyday life, including schooling, and science education. Because science has traditionally been involved with learning about life and bodies and relationships between humans and the living and nonliving environments in which they conduct their lives, we regard mindfulness as central to a transformed science education that includes the science of learning and being in the world.

Cross-References

- ▶ Affect in Learning Science
- ▶ Emotion and the Teaching and Learning of Science
- ▶ Teacher Research

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Mindtools (Productivity and Learning)

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Keywords

Cognitive partners; Concept mapping

Main Text

Early in the evolution of classroom-based computing technologies, Taylor (1980) described three roles that computers could play in the classroom: tutor, tool, and tutee. In the tutor role, the computer teaches the student, a role fulfilled nowadays by Web-based tutorials, information sites, and drill-and-practice. Computers continue to be very powerful productivity tools, including word processing and organizational tools such as databases and spreadsheets. The most constructivist application of computer technologies is in playing the role of tutee, where the students actually teach the computer. One way in which computer technologies can serve as a tutee is by enabling students to construct models of what they are learning. Science educators have long recognized the importance of modeling in understanding scientific phenomena. Humans are natural model builders, constructing conceptual models of everything that we encounter in the world. The better that we understand any part of the world, the better we can model that part of the world – whether it is from science, economics, or how an automobile operates. This entry briefly describes the use of computers as mindtools (Jonassen 2000, 2006) to create models of the ideas that we are learning.

Science and mathematics educators have long recognized the importance of modeling in understanding scientific and mathematical phenomena. Psychologists have explored mental or conceptual models and how these can be represented through external models or visualizations. The models in the minds of learners can be understood as being embodied in the equations, diagrams, computer programs, or other symbolic constructs used by learners to represent their understanding. Although still a topic of research, it is clear that there is a dynamic and reciprocal relationship between our internal mental models and the external models that we construct. The primary purpose of modeling is the construction and revision of conceptual understanding – that is, conceptual change. Building explicit models of our internal conceptual models engages and supports the process of conceptual change. When we build and test external models, our internal models make progress.

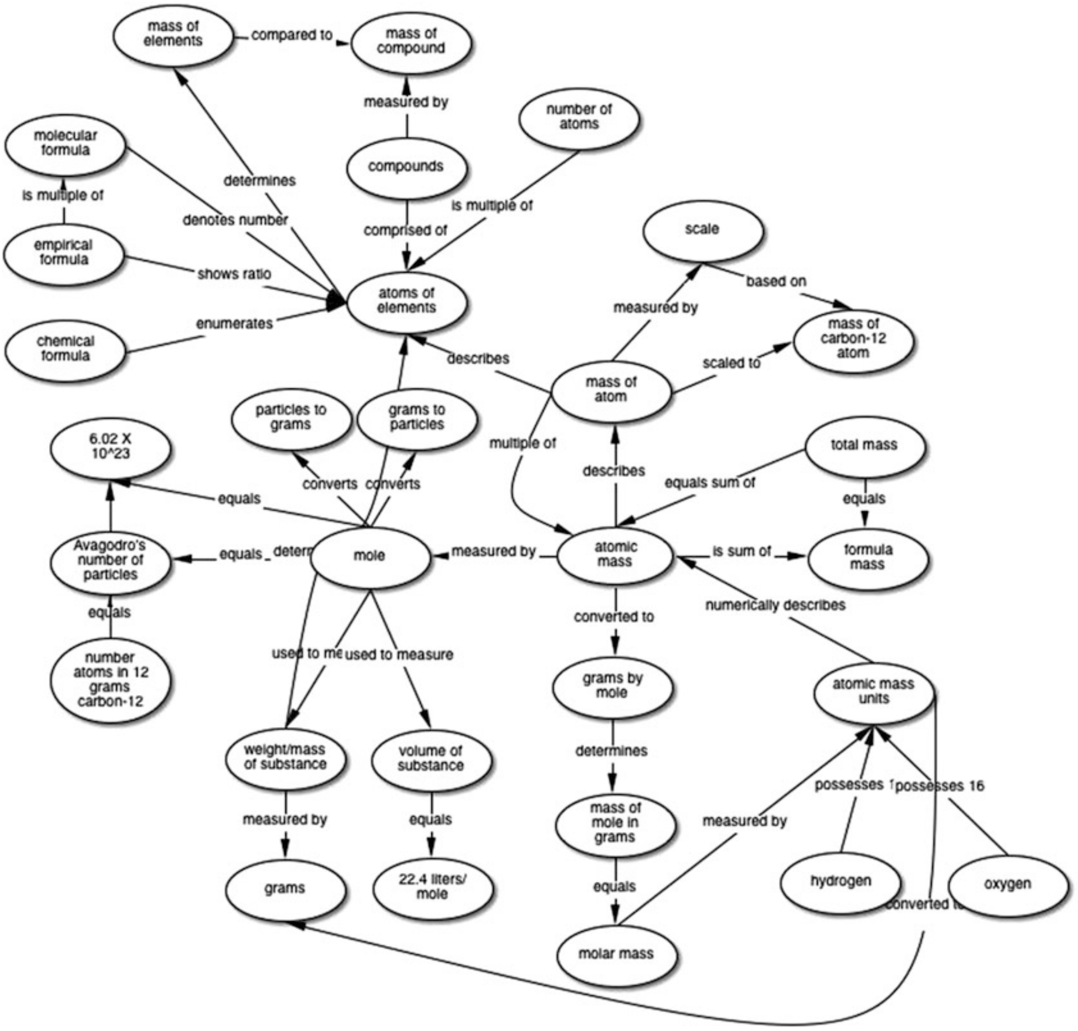
This entry introduces the notion of "mindtools," which are readily available tools for constructing syntactic and structural representations of what is being learned. Mindtools repurpose commonly used computer applications to engage learners in critical thinking and conceptual change. There are several classes of mindtools, including semantic organization tools (e.g., databases, concept mappers), dynamic modeling tools (e.g., spreadsheets, expert systems, or systems modeling tools), visualization tools (e.g., drawing or visual modeling environments), knowledge construction tools (e.g., multimedia construction and story construction tools), and conversation and collaboration tools. All of these tools may be used to construct models of what is being learned.

What Can Be Modeled

If model building serves to externalize mental models, then learners should benefit through the use of a variety of tools to model a variety of phenomena. Different models engage different kinds of thinking, and mindtools may be used to model different kinds of phenomena (Jonassen 2000).

Modeling Domain Knowledge

Domain knowledge is often presented and understood by learners in a very linear fashion, consisting of a series of facts and unrelated pieces. By modeling the domain and its structure, elements can be related to each other in complex associative maps (e.g., concept maps) or causally related systems (e.g., spreadsheets, expert systems, or system models). Concept maps are spatial representations of concepts and their interrelationships that reflect the knowledge held by the learner. Figure 1 illustrates a concept map describing molar conversion in chemistry. These representational structures can also be seen as cognitive structures, reflecting conceptual knowledge, structural knowledge, and semantic networks. As students study some domain in



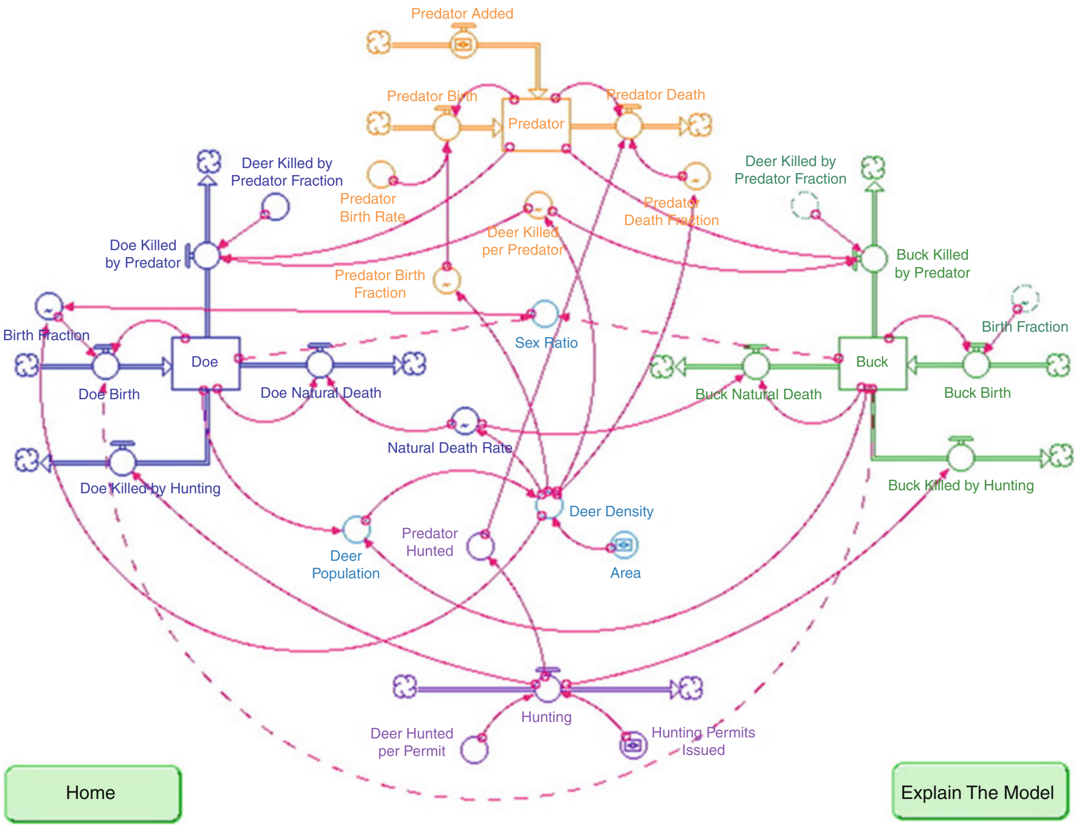
Mindtools (Productivity and Learning), Fig. 1 Concept map on molar conversion

a science course, they can continuously add to their concept maps, refine them, and even use them to reveal gaps or misunderstandings. Comparing one's concept map with others can result in conceptual change, as models constructed by other students can represent alternative structure of the same ideas.

Modeling Systems

Scientific subject matter content can be thought of in terms of coherent systems. Rather than focusing on discrete facts or characteristics of phenomena, when learners study content as systems, they develop a more integrated view of the world. Systems thinking involves understanding the world as process systems, feedback systems, control systems, and living systems, all of which can be seen as self-reproducing organizations of dynamic, interdependent parts. Systems are goal driven, feedback controlled, self-maintaining, self-regulating, and synergetic. Requiring learners to organize what they are learning into relevant interacting systems provides an opportunity to develop a more integrated view of the domain.

Systems and subsystems are defined by structural and causal relationships. Systems modeling tools, such as Stella, enable learners to build



Mindtools (Productivity and Learning), Fig. 2 System model of deer population

models that focus on systems and their internal interactions. Figure 2 illustrates a model depicting the growth and maintenance of a local deer population that was produced by high school students. In this model, we see that the deer population is a function of factors that are part of the larger ecosystems, including reproduction rates that are dependent on predation and hunting. System models show the interactions of components within a system.

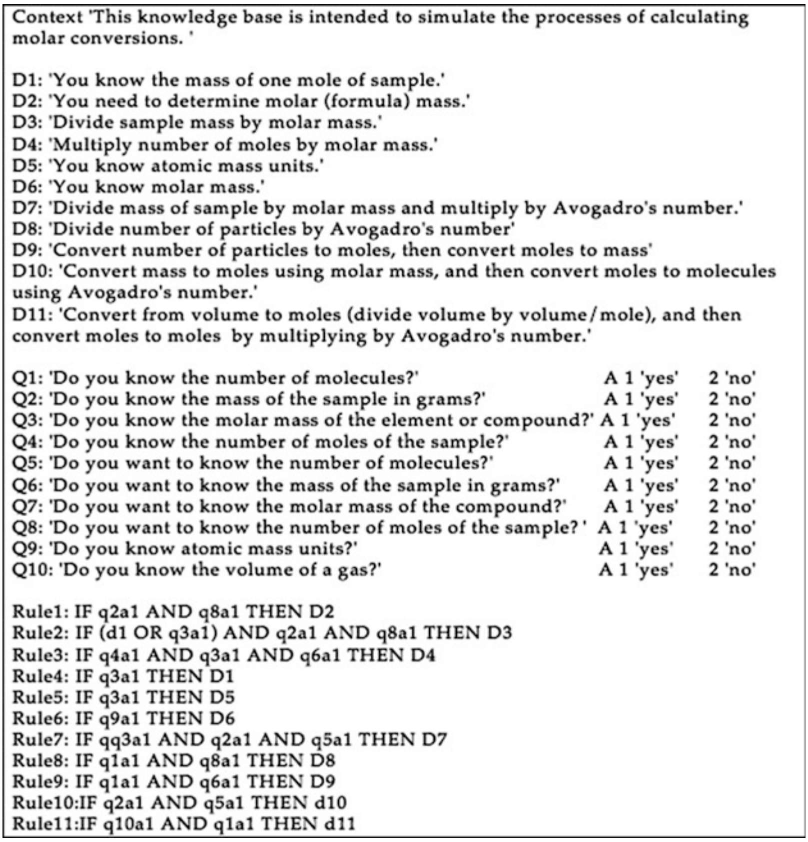
Modeling Problems

In order to solve virtually any kind of problem, the problem solver must mentally construct a problem space by selecting and mapping specific relations of the problem (Jonassen 2006). Using modeling tools to create visual or computational models externalizes learners' mental problem space. As the complexity of the problem increases, producing efficient models becomes even more important. Figure 3 illustrates the advice, factors, and rules to guide the development of an expert system knowledge base relating to how molar conversion problems are solved in chemistry. Reflecting on the problem solution process can help learners to better solve this kind of problem.

Modeling Experiences (Stories)

Stories are the oldest and most natural form of sensemaking. Cultural knowledge is often conveyed through different types of stories, including myths, fairy tales, documentaries, and histories. Humans appear to have an innate ability and predisposition to organize and represent their experiences in the form of stories and can more easily understand stories than expository texts.

An alternative modeling experience to studying content is to collect and study stories that capture relevant disciplinary experiences.



Context 'This knowledge base is intended to simulate the processes of calculating molar conversions. '

D1: 'You know the mass of one mole of sample.'
D2: 'You need to determine molar (formula) mass.'
D3: 'Divide sample mass by molar mass.'
D4: 'Multiply number of moles by molar mass.'
D5: 'You know atomic mass units.'
D6: 'You know molar mass.'
D7: 'Divide mass of sample by molar mass and multiply by Avogadro's number.'
D8: 'Divide number of particles by Avogadro's number'
D9: 'Convert number of particles to moles, then convert moles to mass'
D10: 'Convert mass to moles using molar mass, and then convert moles to molecules using Avogadro's number.'
D11: 'Convert from volume to moles (divide volume by volume/mole), and then convert moles to moles by multiplying by Avogadro's number.'

Q1: 'Do you know the number of molecules?' A 1 'yes' 2 'no'
Q2: 'Do you know the mass of the sample in grams?' A 1 'yes' 2 'no'
Q3: 'Do you know the molar mass of the element or compound?' A 1 'yes' 2 'no'
Q4: 'Do you know the number of moles of the sample?' A 1 'yes' 2 'no'
Q5: 'Do you want to know the number of molecules?' A 1 'yes' 2 'no'
Q6: 'Do you want to know the mass of the sample in grams?' A 1 'yes' 2 'no'
Q7: 'Do you want to know the molar mass of the compound?' A 1 'yes' 2 'no'
Q8: 'Do you want to know the number of moles of the sample? ' A 1 'yes' 2 'no'
Q9: 'Do you know atomic mass units?' A 1 'yes' 2 'no'
Q10: 'Do you know the volume of a gas?' A 1 'yes' 2 'no'

Rule1: IF q2a1 AND q8a1 THEN D2
Rule2: IF (d1 OR q3a1) AND q2a1 AND q8a1 THEN D3
Rule3: IF q4a1 AND q3a1 AND q6a1 THEN D4
Rule4: IF q3a1 THEN D1
Rule5: IF q3a1 THEN D5
Rule6: IF q9a1 THEN D6
Rule7: IF qq3a1 AND q2a1 AND q5a1 THEN D7
Rule8: IF q1a1 AND q8a1 THEN D8
Rule9: IF q1a1 AND q6a1 THEN D9
Rule10:IF q2a1 AND q5a1 THEN d10
Rule11:IF q10a1 AND q1a1 THEN d11

Mindtools (Productivity and Learning), Fig. 3 Excerpt from expert system rule base on molar conversion

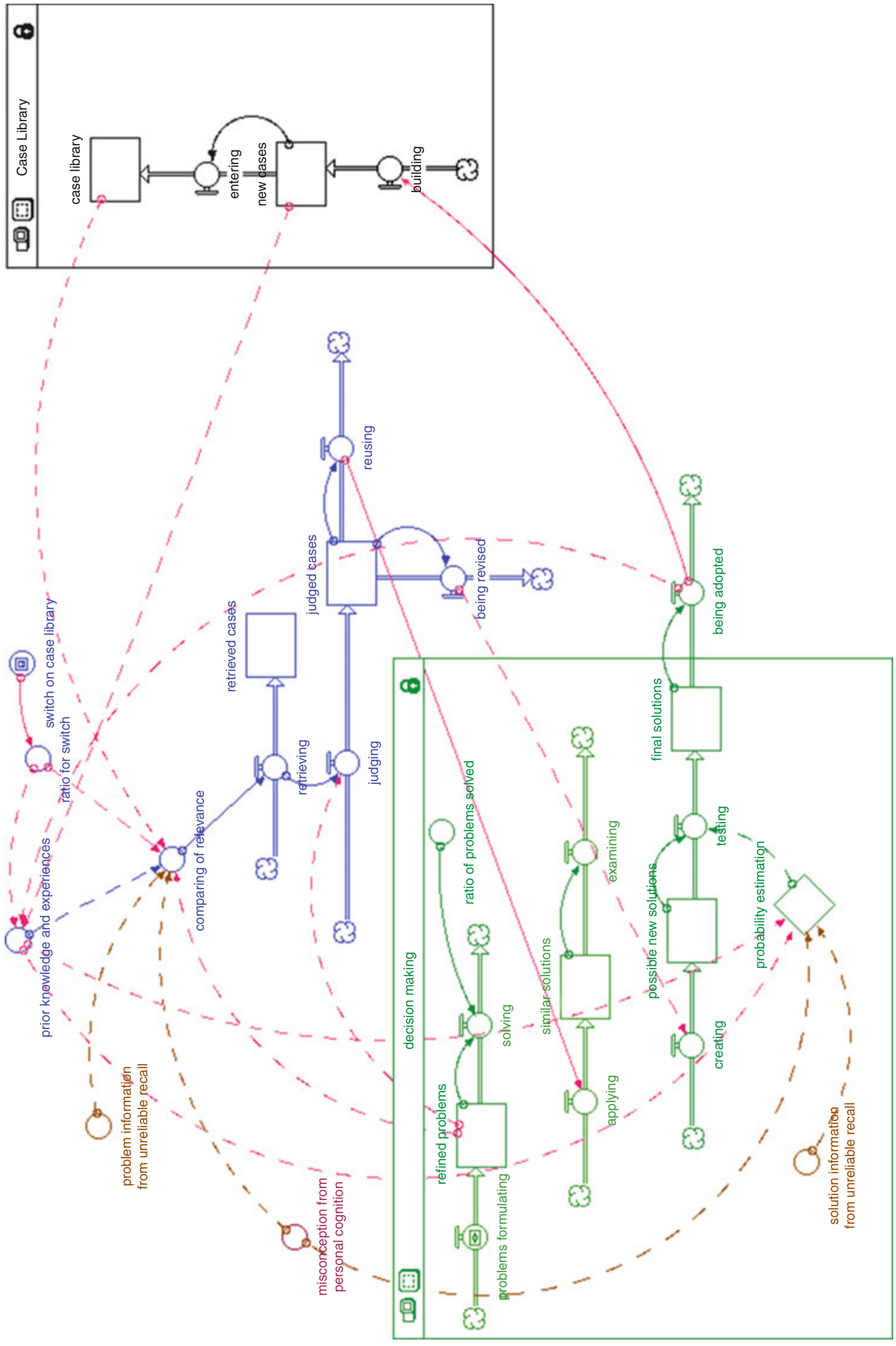
For example, we have constructed databases of stories about how engineers solve different kinds of problems, which have been collected into case libraries (i.e., databases of stories). When studying how to solve problems in any domain, students' understanding may be enriched by such stories that help them to identify the lessons learned from each problem-solving situation. This process is known as case-based reasoning – the reuse of prior experiences. Databases are a logical means for capturing and storing such stories or problem-solving cases, and the process of collecting and indexing them serves to enhance the overall intellectual resource.

Modeling Thinking (Cognitive Simulations)

Many educators have argued for an emphasis of metacognition and self-reflection by learners, having students reflect on their learning processes in order to better learn how to learn. Metacognitive reflection may be enhanced by building a model of how to engage in different kinds of learning. Rather than modeling content or systems, learners can model the kind of thinking that they need to perform in order to solve a problem, make a decision, or complete some other task. Figure 4 illustrates a systems model of decision-making that is based on the case-based reasoning theory just presented. These students developed a model of decision-making, a common form of problem solving and how it is supported by stories of prior experiences.

Why Should We Use a Mindtools Approach?

Why do mindtools work? That is, why do they engage learners in critical, higher-order thinking and facilitate conceptual change? The process of articulating what we know in order to construct a model forces us to reflect on what we are



Mindtools (Productivity and Learning), Fig. 4 Cognitive simulation of decision-making supported by case-based reasoning studying in new and meaningful ways. The common homily, "the quickest way to learn about something is to have to teach it," explains the effectiveness of mindtools, because learners are teaching the computer when constructing models. Mindtools are not intended to make learning easier. Learners do not use mindtools naturally and effortlessly. Rather, the use of a mindtools approach typically requires learners to think harder about the subject matter domain than they would by simply studying its content.

Knowledge Construction, Not Reproduction

Mindtools represent a constructivist use of technology, as they are concerned with the process of how we *construct* knowledge from our experiences. When students develop databases, for instance, they are constructing their own conceptualization of the organization of a content domain. How we construct knowledge depends upon what we already know, which depends on the kinds of experiences that we have had, how we have organized those experiences into knowledge structures, and what we believe about what we know. This does not mean that we can comprehend *only* our own interpretation. Rather, we are able to comprehend a variety of interpretations and to use them in further constructing our understandings.

Constructivist approaches to learning strive to create environments where learners actively participate in ways that help them construct their own knowledge rather than having the teacher try to ensure that students understand the world as they have been told. In a mindtools environment, learners are actively engaged in interpreting the external world and reflecting on their interpretations. This is not "active" in the sense that learners actively listen and then mirror the *one* correct view of reality but rather "active" in the sense that learners must participate and interact with the surrounding environment in order to create their own view of the subject. Mindtools function as formalisms for guiding learners in the organization and representation of what they know.

Learning *with* Technology

The primary distinction between computers as tutors and computers as mindtools was best captured by Salomon, Perkins, and Globerson (1991) as the effects *of* technology versus the effects *with* computer technology. Learning *with* computers refers to the learner entering an intellectual partnership with the computer. Learning *with* mindtools depends "on the mindful engagement of learners in the tasks afforded by these tools and that there is the possibility of qualitatively upgrading the performance of the joint system of learner plus technology" (p. 2). In other words, when students work with computer technologies, instead of being controlled by them, the students enhance the capabilities of the computer, and the computer enhances the students' thinking and learning. The result of such an intellectual partnership with the computer is that the whole of learning becomes greater than the sum of its parts.

Cross-References

- ▶ Argumentation Environments
- ▶ Concept Maps: An Ausubelian Perspective
- ▶ Modeling Environments
- ▶ Scientific Visualizations
- ▶ Simulation Environments
- ▶ Technology for Science Education: History
- ▶ Technology for Science Education: Research

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Model of Educational Reconstruction

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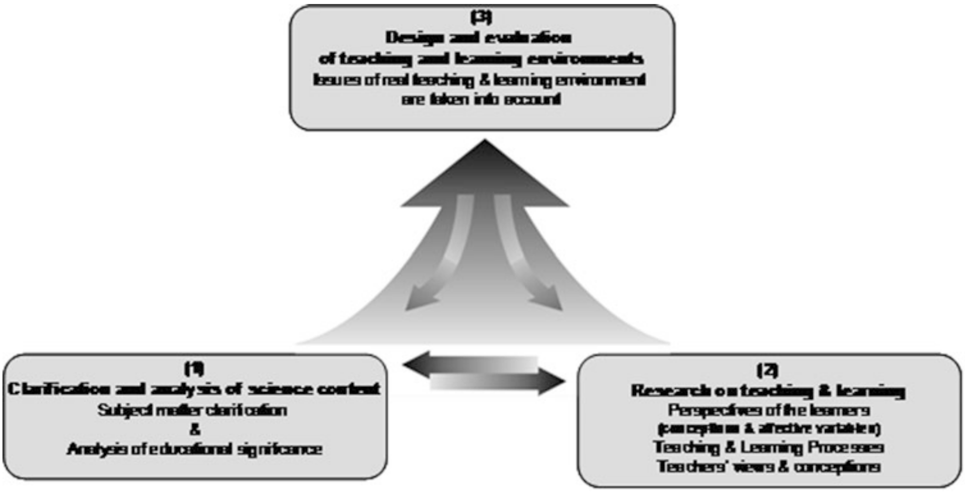
A key feature of the *Educational Reconstruction* approach is that in planning instruction – by teachers or curriculum developers – the science content to be learned *and* students' cognitive and affective variables, including their learning processes, should be given equal attention. In addition, the science content is not viewed as "given" but has to undergo certain *reconstruction* processes. The *science content structure* (e.g., for the concept of evolution) has to be transformed into a *content structure for instruction*. The two structures are fundamentally different. The first step in this reconstruction, called "elementarization" (in German, Elementarisierung), is to identify the elementary ideas that relate to the aims of instruction, taking into account student perspectives (e.g., their pre-instructional conceptions). Then the content structure for instruction has to be developed. Finally, teaching and learning settings have to be designed. The tendency of many approaches aiming at more efficient science instruction to put the major emphasis on just instructional methods should be seen as problematic.

The Model of Educational Reconstruction (MER) (Fig. 1) draws on these basic ideas (Duit et al. 2012). It is based on European Didaktik and Bildung (formation) traditions – with a particular emphasis on the German tradition (Westbury et al. 2000). It has been developed as a theoretical framework for studies looking at whether it is possible and worthwhile to teach particular science content areas. Clarification of science subject matter – including science concepts, views about the nature of science, and also the relevance of science in daily life and society – should be given substantial attention when developing instruction of a particular science content. In the past, however, often the main (or even the only) issues informing the clarification process are those that come from the structure of the science content involved. Educational issues are considered only after the science subject matter structure has been clarified.

The MER closely links analyses of the science content structure and the educational significance of parts of it, with empirical studies of students' understanding and with preliminary trials of pilot instructional modules in the classroom. It is a key assumption of the model that the curriculum developers' awareness of the students' points of view may substantially influence the reconstruction of the particular science content. The MER has been designed primarily as a frame for science education research and development. However, it also provides useful guidance for planning instruction in school practice.

The core of the model is the analytical process of transposing (or transforming) human knowledge (i.e., the cultural heritage), such as domain-specific scientific knowledge, into knowledge for schooling that contributes to students' scientific literacy. The science content structure cannot be directly transferred into a content structure for instruction. It has to be "elementarized" to make it accessible for students, but also enriched by putting it into contexts that make sense to the learners. Figure 1 illustrates the fundamental interaction between the three components of the MER. They influence each other mutually. Consequently in practice the result is a complex *recursive* step-by-step process.

The MER shares major characteristics with other models of instructional design. In French science and mathematics education, the conception of *Transposition Didactique* includes similar ideas about the process of transposing human knowledge. The MER is explicitly based on constructivist views about efficient teaching and learning environments. The cyclical (recursive) process of educational reconstruction, i.e., the process of theoretical reflection, conceptual analysis, small-scale curriculum development, and classroom research, is also a key concern of *Developmental Research*, of *Design-based research* (Cobb et al. 2003), and of other efforts to implement more evidence-informed approaches to teaching and learning in science. There is also a significant overlap with the idea of *Teaching and Learning*



Model of Educational Reconstruction, Fig. 1 The three components of the Model of Educational Reconstruction (*MER*)

Sequences as discussed by Meheut and Psillos (2004). For all such approaches, research and development are intimately linked, and the conditions of teaching and learning in instructional practices (in schools and elsewhere) are explicitly taken into account. The MER also shares major features with the *Learning Progression* approach that has developed in the past decade, primarily in the USA (Duschl et al. 2011).

In a nutshell, the MER shares major features with other frameworks of science education research and instructional design. The particular contribution of these frameworks is the idea that science content structure has to be reconstructed on the basis of educational issues, i.e., the aims of instruction and students' perspectives.

Cross-References

- ▶ Bildung
- ▶ Developmental Research
- ▶ Didaktik
- ▶ Evidence-Informed Practice in Science Education
- ▶ Learning Progressions
- ▶ Teaching and Learning Sequences
- ▶ Transposition Didactique

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Modeling Environments

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Main Text

Modeling environments are computational tools that support learners in building dynamic or static models that represent phenomena such as plant growth, the solar system, or crowd behavior. In the context of a well-designed curricular activity, the learner creates the model by specifying objects, their characteristics (i.e., variables), and their relationships. Relationships can be specified in different ways depending on the learning environment. Modeling tools such as concept maps or causal loop diagrams allow the learner to specify relationships qualitatively. In concept maps, relationships can be specified by describing the nature of the relationship (e.g., "is a"). In causal loop diagrams, relationships are specified by polarities (i.e., "+" and "−") and include feedback loops describing how one variable causes a change of another variable, which then causes a change of the original variable. Some modeling environments allow learners to not only specify relationships but also to run the models, revealing potentially unexpected behaviors and allowing learners to test their predictions. In executable modeling environments, the learner can observe how values of variables change over time.

Modeling Languages

Executable modeling environments are different from simulation environments because of the ability to create a model of a dynamic system and to study it in a quantitative way. Executable modeling environments are based on a formalized language such as Petri nets, NetLogo, or System Dynamics, allowing the learner to quantitatively specify variables and relationships. System Dynamics, a modeling language developed by Forrester (1961), has been frequently used in learning settings. It is developed to represent dynamic systems (e.g., population growth) and to predict and understand relationships between variables (e.g., death rate and birth rate) over time. System Dynamics, like other languages, makes use of generic variable types to simulate direct and indirect effects of variables within complex systems.

Inquiry Learning

Modeling has been the focus of considerable research and is often cited as a central aspect of inquiry learning, where students actively construct their knowledge by specifying relations between variables of dynamic phenomena. For example, as part of an iterative inquiry cycle, a learner might start out with an orientation activity in which information about relevant objects or variables is sought and a research question is formulated. During an initial hypothesis activity, students would be supported in creating a model that embeds their hypothesis. In an ensuing experimentation activity, variables of a model could be modified for the purpose of testing the hypothesis. In the results activity, the produced data is analyzed and interpreted by the learner, allowing inferences. Based on those inferences or conclusions, a new hypothesis or research question could be formulated, beginning a new inquiry cycle.

Example Environments

Modeling environments are designed to work either as stand-alone tools or as activities embedded within a broader learning environment, where learners create models as part of an inquiry project. Stand-alone tools like Model-It (Krajcik and Blumenfeld 2006) or STELLA (Steed 1992) allow the learner to build executable models. They are typically integrated by the researcher or teacher, into a substantive curriculum unit, requiring careful design of activities. An embedded approach, such as employed by Co-lab (van Joolingen et al. 2005), includes a modeling activity within an overarching technology-supported learning environment. Co-lab uses the metaphor of buildings that includes different houses and rooms to guide the learner through activities of an inquiry process. The Web-based Inquiry Science Environment (WISE) (Slotta and Linn 2009) offers modeling tools in combination with notes, hints, domain information, and data visualization tools, which are provided in the context of project-based inquiry.

Applications for Learning

In its application as a learning activity, modeling has been studied in various domains, including water flow, thermodynamics, and ecosystems, and real-world phenomena such as traffic flow. Research has shown that modeling environments allow the learner to appreciate the value of models and the role that models play in science. Learners become aware that models play a role in scientific reasoning. When models no longer meet their purpose, they must be updated or replaced with better ones. This restructuring process helps learners to refine their understanding of the complex nature of scientific phenomena and the scientific inquiry process. In terms of learning outcomes, modeling environments have been shown to foster learning of complex topics. For more simple topics, other learning environments such as simulations or more traditional forms of instruction are more effective.

Cross-References

- ► Concept Mapping
- ► Inquiry, Learning Through
- ► Simulation Environments

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Modeling Teaching

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Keywords

Modeling teaching

Introduction

Modeling is the act of sharing through explicit demonstration a particular skill, practice, activity, or way of thinking. Modeling teaching involves showcasing teaching practice, as well as the reasoning that informs, and the language that explains that practice. Effective modeling has been shown to enhance learning-to-teach science in elementary, secondary, and postsecondary settings.

Modeling teaching is a highly flexible strategy that can illustrate how to plan lessons; how to design and implement diverse instructional strategies such as inquiry teaching, lecturing, hands-on laboratory sessions, and learning beyond the classroom (e.g., in field trips and other informal contexts); and how to assess student understanding before, during, and after instruction. Modeling can also be used to illustrate the application of theory in the practice of teaching and to encourage and assist preservice teachers in acquiring skills in reflective practice (Loughran and Berry 2005).

Modeling Is a Guide, Not a Recipe

A challenge associated with the use of modeling teaching as a strategy is that any given episode can only highlight certain aspects of a topic, issue, theory, thought process, or practice. The observer or novice teacher may misinterpret a modeling episode intended to show how a topic *might* be taught, to mean this is how that topic *must* be taught. For example, modeling the constructivist teaching approach of probing prior knowledge of students for a particular science concept may be misconstrued to indicate that every science concept one teaches will require such probing. Similarly, modeling the use of teaching approaches such as concept mapping for reviewing topic "X," or role playing for promoting an embodied understanding of a particularly complex scientific process, may lead novice teachers to link the modeled teaching approach with the particular topic used in the exemplar or to broadly apply the modeled practice to topics where it will not assist with student learning.

To address this issue, it is essential that all modeling of teaching be accompanied by some conversation about the practice or practices that were modeled. Debriefing of a modeled episode needs to incorporate reflection and participation by the preservice teachers, as well as explicit discussion of the instructor's intentions or a conversation on teaching about teaching by the educators who undertook the modeling. This combination of dialogic debrief elements avoids the educator adopting (and modeling) a "teaching as telling, showing, [and] guided practice approach" (Myers 2002, p. 131).

Learning Through Modeling

Modeling of both "good" and "bad" teaching has merit, but both types of exemplars must be accompanied by discussions of practice. Modeling of poor practices with preservice teachers participating as students can provoke thinking and discussion about teaching and learning issues that may be invisible and tacit and thus missed in "good" and effective instructional exemplars. For example, modeling teaching of a laboratory activity where the required materials are not all available, are poorly labeled, or are not distributed on the laboratory bench, where safety concerns are handled cavalierly, and where students are rushing to complete the laboratory and data recording can lead to rich discussions of the important safety, organization, and learning elements of hands-on laboratory lessons.

Both the modeling of teaching and learning from that modeling require skills and practice. Novice teachers as observers of modeled episodes need skills in order to see and understand what is happening. To assist and scaffold such learning, teacher educators should establish a "safe," trusting classroom environment where talk about teaching is encouraged and happens regularly and guidelines for how to offer honest feedback in a positive and supportive manner are provided.

Conclusion

The intentional and explicit modeling of teaching, the ability to "unpack" that teaching without being didactic, and modeling the critique of teaching for the learner are complex processes that contribute to the development of teacher educators and represent a form of professional knowledge that is researched through the self-study of teaching and teacher education (Loughran and Berry 2005). Thus, modeling teaching informs not only those who are learning to teach but also those who do the modeling of practice.

Cross-References

- ▶ Identity of Teacher Educators
- ▶ Pedagogy of Teacher Education
- ▶ Teacher Educator as Learner
- ▶ Teacher Professional Development

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Models

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Keywords

Explanation; Mechanisms; Representations; Scientific reasoning

Science is fundamentally about coming to understand the world in both its complexity and amazing elegance. At its core it is about developing explanations for the workings of the natural world based on evidence. Science is a particular way of approaching the generation, evaluation, and revision of knowledge that has served as the foundation for profound shifts in our collective understandings and our manipulation of the world.

Models are viewed by many as the functional units of scientific thought. They allow the scientist to reason about a phenomenon by representing and highlighting aspects of that phenomenon that are salient to answering questions about how and why the phenomenon works the way it does. They take a small number of theoretical ideas and highlight the key relationships among them making it possible to reason with the ideas to address questions and problems in the discipline (Giere 1988). Models – sets of ideas that define relationships among various theoretical and concrete objects and processes – are ubiquitous in science. Some examples of important and familiar models include the model of the atom, the model of the particulate nature of matter, the model of plate tectonics, and the model of protein synthesis. Models function as reasoning tools that allow one to bound, explore, organize, and investigate phenomena and to develop explanations, generalizations, abstractions, and causal claims about those phenomena.

The verb modeling refers to the acts of generating, evaluating, revising, and using/applying models. Modeling is, at its core, about making sense of the world by producing and coupling theoretical interpretations and understandings with empirical measurements/observations in order to develop explanations and predictions about phenomena.

Consistent with its centrality in scientific reasoning, modeling is now recognized as a key practice that can be used to organize and structure classroom science from the elementary grades through graduate school, and likewise core disciplinary models can serve as the foundation for content organization of science education. Thus, just as models and modeling are often at the center of accounts of scientific practice, an explicit focus on models and modeling is becoming more common in science education.

Models

Models are sets of ideas about why particular classes of phenomena function the way they do. They exist on a continuum between nascent and naïve ideas in an individual's mind – often called mental or internal models – and clear and widely shared ideas that guide a community of scholars in a particular field, often called expressed or conceptual models. They provide an important foundation for scientific thought.

Models are human constructions that stipulate a set of relationships between and among observed or theoretical processes, events, and objects. Models can be used to figure out and understand how something works. For example, a model for the particulate nature of matter stipulates relationships between small bits of matter (atoms). Such a model would include the core stipulation that the matter in the world is made up of tiny, unseen particles and that those particles interact with one another in specific ways. From this model (the set of ideas about how particles behave), one can understand and explain a broad class of phenomena from phases of matter to how smell travels across a room.

The level of detail and the particular attributes of a model are dependent upon the aim of the modeler, and therefore, there may be many models for reasoning about any particular phenomenon. Take again the case of the particulate nature of matter. Depending on what the modeler is using the model for, the model may invoke a generic particle, or it may invoke those particles as atoms and molecules with particular attributes (e.g., polarity).

The model is a dynamic mental entity that can be used to explain and predict phenomena. Determining the relationships among the model ideas is what enables a model to function as a reasoning tool. Even though the word model is used in general parlance to refer to purely descriptive depictions, in science, something does not function as a model unless it can be used to reason about the underlying causes of a phenomenon. In this sense, models sit between theory and evidence.

Within a community of practice, a model must be externalized and communicated in order to undergo evaluation and be used by the community. The externalized model can take a range of representational forms depending on the aim of the modeler and the purposes to which the model is being put to in a particular context. Many models that contain the same core conception of a system can be alternatively represented in diagrammatic, narrative, and/or mathematical forms. However, it is not the expressed form that makes something a model or not; rather it is the way in which the underlying ideas are used toward a goal of sensemaking that defines a model.

Models are subject to evaluation based on conceptual as well as empirical criteria. Model evaluation based on conceptual criteria involves comparing the model to previously agreed upon theoretical ideas or other models. Typically, scientists strive for consistency among the models in their discipline such that the assumptions in one model do not violate or contradict those in another. While this is a common criterion to use for evaluation, there are some times when two contradictory models may be held by the community and used in different circumstances because each has some utility in explaining or predicting empirical data. Perhaps the most notable instance of this in physics is the continued use of both particle and wave models of light.

Empirical criteria are applied when comparing a model or the explanatory output of the model to observations and data. The scientist asks if the model is useful in explaining the data at hand, and in some cases the predictive power of the model is used to evaluate the utility of the model. It is the correspondence between the model and the phenomenon that is key to empirical model evaluation, and in that sense a model can be thought of as a representation of particular aspects of the phenomenon.

Modeling

Models are at the core of scientific reasoning. They hold the theoretical ideas of the reasoner in a clarified arrangement that allows her/him to make sense of the world. Models mediate between the more abstract and very general theoretical ideas in a field and the empirical world. The act of modeling includes developing, examining, critiquing, and using these sets of ideas. Modeling is the active process of putting discrete ideas together by stipulating the relationships between and among them. Modeling is also the act of examining the utility of the model in the face of some sensemaking need. In this case the ideas are held up and examined for their fruitfulness. This may result in particular ideas or relationships being kept as is, discarded, or modified. This analysis and revision process is one form of modeling. And finally, when a scientist is using the model and applying it in a deliberate way to a phenomenon, she/he is modeling.

Functions of Models

Models serve a variety of functions and are central to the day-to-day working and reasoning of most scientists (Osbeck et al. 2010). In some disciplines models are named with the word model and the modeling is explicit. In others the role of the model may be more implicit, but in virtually all cases there is a small set of ideas that are at the core of particular scientific activities.

Models are used in practice to define and develop questions, they often point to specific investigations and data collection needs, they form the basis of explanations and predictions, and they are key to communicating about the processes that underlie observable phenomena. Thus, models inform and mediate a range of activity in science, and in turn these activities become the basis of further model development and refinement.

Scientists alternate between interacting with the physical world and developing models that explain measurements and observations. Extant models play a key role in helping to define the scope of observations. They become important filters on the world that affect what the scientist notices and finds worthy of investigation. In this way, models that already exist in a discipline are an important element in the generation of questions worth pursuing. For example, if one was interested in explaining the existence of particular trait variations in a population of organisms, the aspects of that phenomenon that are salient would depend in large part on the models that the phenomenon was viewed through. If the investigator was operating with evolutionary models, the observations and questions asked would differ from those asked from the perspective of physiological models.

As scientists use their models to ask questions about the world, they must both incorporate and generate data in a systematic way. The model often assists the scientist in considering what kind of data would be useful, and in this way, models provide a foundation for investigations in science. Since models incorporate the current understanding of a phenomenon, they form the basis of the scientist's interactions with that phenomenon.

Once an investigation is complete, the data generated are analyzed with regard to the model, and the model is evaluated with regard to the data. That is, the scientist seeks to understand the data with regard to the model, incorporates the empirical results into the model, and uses those results to inform further refinements of the model.

Models are developed with respect to a particular phenomenon or class of phenomena. In this way many models begin in a rather specific state. However, the aim of the modeler is to explain a broader swath of the world, and thus, models developed in one context can be taken to other contexts, tested for their fruitfulness, and often revised once again. The common use of model organisms in the biological sciences is a case in point. Scientists investigate the workings of particular organisms in order to first understand how processes and mechanisms work in that species. Then they use that understanding as a basis for explaining similar attributes across a wider range of organisms. A model for a specific metabolic pathway in one species, for example, may then be revised or broadened when taking into account how the system works across several species.

Models and Modeling in the Science Classroom

In science education the term models has been used to refer to a wide class of objects. Science teachers often refer to objects in their classrooms such as plastic torsos and Styrofoam ball depictions of the solar system as models. Teachers also often talk about modeling particular behaviors for students in the sense that they show them what to do or how to do it. While these uses of the word model and modeling are legitimate uses in education, in terms of scientific practice, models and modeling take on a much more specific meaning as explicated above. Merely depicting or describing a system should not be the endpoint of activity because science is centrally concerned with understanding and exploring the mechanisms that underlie the observable world.

An explicit focus on models and modeling in the science classroom is becoming more common (Windschitl et al. 2008). Classroom teachers have crafted experiences for students that make the model-based sensemaking that scientists do accessible and attainable for children across grade levels (Schwarz et al. 2009). One curricular area that is commonly taught with an explicit focus on models and modeling is around the particulate nature of matter. This example can illustrate how classrooms can be centered on model-based sensemaking and how a focus on models and modeling can productively organize classroom activity in much the same way that it organizes scientific activity.

Imagine a middle school classroom in which the students are investigating the attributes of matter. The curricular unit begins with some concrete experiences and a focus on a few phenomena like the movement of a smell across the room, the way a drop of food coloring disperses in a glass of water, and the phase changes of water. With the assistance of the teacher, the students are pushed to wonder what it is about the nature and structure of matter that would help them explain these phenomena. Over the ensuing days, they experience more phenomena and are introduced to and develop the ideas of particles and their movements and interactions. This can play out in classrooms in a wide variety of ways, but the key feature of this experience must be that students come to a deep understanding of the various aspects of the model, that they develop and elaborate the core stipulations in the model as a community, and that they work to test those ideas against phenomena by using them to explain the phenomena that motivated their investigations.

This kind of classroom is in stark contrast to one where students are told that the world is made up of small particles, called atoms and molecules, and asked to repeat that fact on a test. On the surface these two contexts may appear similar in that in each classroom one goal is for the students to emerge with the knowledge that matter is made of particles. However, in the classroom in which this idea is presented to students in its final form and assessed as a fact, the students have not experienced using the ideas as a tool for making sense of the world nor are they likely to understand their utility in explaining phenomena. On the other hand, when the exploration of matter is motivated by asking questions about phenomena and the road to answering those questions is through clearly articulating a model for the underlying mechanisms that can be used to explain those phenomena, the students may achieve something more than simply knowing the definition of atoms and molecules. Modeling provides an opportunity for students to connect sets of ideas together, thus making it possible for them to construct a rich understanding of the phenomena in the context of an explanatory framework.

Designing classrooms that are model based involves a shift both in pedagogy and in content organization. Classrooms that are model based focus on the connections between theoretical ideas and observable phenomena and can provide opportunities for students to use models to develop explanations and engage in argumentation (Passmore and Svoboda 2012). This implies that the teacher must craft an environment in which students are active learners in a community setting and that scientific concepts are not presented as discrete facts.

Summary

A focus on models and modeling has become more prominent in science classrooms. This focus has come as science educators have made deliberate attempts to build science experiences that mirror important aspects of scientific practice. Because modeling is central to reasoning in science, it provides an important framework for engaging students in scientific reasoning. Model-focused science classrooms provide students with opportunities to make sense of the world by developing, representing, sharing, and applying models.

Cross-References

- ▶ Communities of Practice
- ▶ Mechanisms
- ▶ Multimodal Representations and Science Learning
- ▶ Scientific Visualizations
- ▶ Visualization and the Learning of Science

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Morals and Science Education

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Science and conscience have a vital, if sometimes uneasy, relationship. Moral education demands levels of responsible agency that science education does not, owing to the shift from what *is* the case to what *ought* to be the case. Facts and causes are the domain of science and values and duties the domain of ethics; but criticism is equally requisite in both. Science and ethics alike are embedded in traditions where truths are shared through education. Ethicists often find stages in moral life; no analogous claims have been made for scientific life. Morality has to be chosen, entered into, lived, and practiced, in ways that science does not. People are responsible for their values as they are not for their science.

Astronomy is sometimes thought to leave humans lost and lonely among the stars, and this may leave puzzles where to place Earthbound human morality in a vast meaningless universe. “The more the universe seems comprehensible, the more it also seems pointless” (Weinberg 1988, p. 154). More recently physics has made dramatic discoveries at astronomical and submicroscopic ranges, such as the formation of elements in the stars involving microphysical process, such that the midrange scales, where the known complexity mostly lies (in ecosystems or human brains), depend on the interacting microscopic and astronomical ranges. This “anthropic principle” endorses and even celebrates human cognitive and moral powers. We humans do not live at the range of the infinitely small, nor at that of the infinitely large, but we may well live at the range of the infinitely complex. That restores human dignity and worth (Barr 2003).

Biological sciences often carry implicit or explicit overtones of who and what humans are, which may not be coherent with the implicit or explicit human self-understandings in classical or contemporary moral education. Human behavior is shaped by selfish genes (Dawkins 1989); we should biologicize ethics as disguised self-interest (Wilson 1975, p. 562). If so, can humans be altruistic? Scratch an “altruist” and watch a “hypocrite” bleed (Ghiselin 1974, p. 247). Ethicists may agree about selfish tendencies in human nature but argue that humans can and ought to be educated toward a common good, or at least more enlightened self-interests. Theologians may find that humans are in need of redemption. Meanwhile, biologists may find more cooperation coded into the human genome than previously thought (Nowak and Highfield 2011).

The sciences may also open up new possibilities (cloning, genetically modified genes; Bruce and Bruce 1998) or threats (climate change, mass extinction; Gardiner 2011) with which inherited moral systems are unfamiliar. Moral education may enlighten and elevate the human nature that has evolved biologically (Campbell 1976).

By prevailing Darwinian accounts, biological natural history results from natural selection, which is thought to be blind, both in the genetic variations bubbling up without regard to the needs of the organism and in selection for survival, without regard to advance. Other biologists hold that such behavior can be more positively interpreted. Organisms defend their lives; their so-called selfishness is really self-actualizing, the defense of vitality. Reproduction is the ongoing sharing of biological value and promise. The genes function to conserve life; they also make possible a creative upflow of life struggling through turnover of species and resulting in more diverse and complex forms of life over millennia.

Such biologists emphasize the continuing vital creative processes over time, the ascent of life from the simple to the complex, a prolific (pro-life) biosphere, the conservation and elaboration of genetic information, and the effective and efficient results of genetic creativity and natural selection. This may lead to a sense of respect for life, made possible by our human singularity, the sole species with moral powers, and with responsibility for caring for other humans and for the Earth.

Reinterpreting natural history more constructively may also have implications for human self-estimates. Humans evolved from prehuman primate ancestors; we may be told that we inherit a monkey's mind. "DNA evidence provides an objective non-anthropocentric view of the place of humans in evolution. We humans appear as only slightly remodeled chimpanzee-like apes" (Wildman et al. 2003, p. 7181). But humans have over three times the brain size of chimps, so that a 3 % difference in protein structures makes 300 % bigger brains. Cognitively, we are not 3 % but 300 % different (Marks 2002, p. 23).

When you compare Einstein with a chimp, it does not appear that Einstein is only slightly remodeled; nor do we wonder whether an atomic bomb built with his theory that $E = mc^2$ is a slightly remodeled ant-fishing stick. An explosion of cognitive powers emerges with the human mind, an event otherwise unknown in natural history. Neurosciences may agree that the human mind is immensely complex and also find openness and mutability (in synaptic connections) that permits humans to be morally responsible (Merzenich 2001). "We are hugely different. … the differences are light years apart" (Gazzaniga 2008, p. 13).

The ecological sciences will add that on Earth humans are (and ought to be) at home, the root idea in ecology. A moral priority is a sustainable biosphere. Ecologists also find that humans are degrading the biosphere. They may be apprehensive about ecosystem services or impending extinctions (Millennium Ecosystem Assessment 2005). They will demand education in conservation biology. No one is rational if he or she is neutral, dispassionate, about one's home. One is immoral if unconcerned about life in jeopardy on one's home planet. Biologists are almost unanimous in their respect for life on an endangered planet. The Earth's impressive and unique biodiversity warrants wonder and care.

In both science and moral education, one seeks enlightenment. Philosophers may push the claim that modern science, after 400 years, still leaves the ultimate value questions urgent and unresolved. Indeed, there is no scientific guidance of life. The value questions remain as acute and painful as ever.

Cross-References

- ▶ Biology, Philosophy of
- ▶ Cultural Values and Science Education

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Motivation and the Learning of Science

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Keywords

Achievement goals; Engagement; Lifelong learning; Motivation; Self-determination

Introduction

Why is motivation so important? Learning is typically the result of intellectual, emotional, and physical engagement, and engagement is an outcome of motivation. Without motivation there is little engagement, and without engagement, little learning can occur. This is true in general, not only for the learning of science; one is not likely to become proficient at tennis, carpentry, or any intellectual activity unless one is motivated, for whatever the reason, to become proficient at these activities.

While motivation is a necessary condition for learning to occur, it is also a desired outcome of learning. Knowledge is like a skyscraper, each level built on the foundations provided by the lower levels. However, for the construction to continue beyond a certain level, there needs to be motivation to do so. Thus, for example, one can learn about Rutherford's model of the atom and be content with this knowledge, without any desire to learn more about the atom. Moving on to the next level (perhaps Bohr's model of the atom, in this case) requires the motivation to go further. This motivation can be developed and fed by the process of learning about Rutherford's model. Thus, learning and motivation are intertwined – the first seldom occurs without the second and the second needs to be fostered by the first for learning to continue.

Theories of Motivation

There exist several theories of motivation (Schunk et al. 2008) – expectancy-value theory, attribution theory, self-determination theory, and achievement goal theory. While none of these theories were developed specifically for use in science education, they have all been applied in the context of science education.

Expectancy-value theory in science education addresses the combined effect of the perceived value of learning a science topic and the expectation of succeeding to learn it, so

$$\text{Level of motivation} = \text{perceived value} \times \text{success expectancy}$$

One's success expectancy is directly related to one's perceived self-efficacy in science, while the perceived value of learning a topic is related to the cost involved in learning the topic (time, effort, negative feelings), the interest in the topic and the pleasure involved in learning it, the practical value of understanding the topic, and if the learning of the topic supports the attainment of personal needs (social acceptance, values, identity).

Attribution theory attends to the perceived attributes for success or failure at a task related to learning, such as talent, perseverance, luck, difficulty of task, etc. Each of these attributes has three dimensions:

(a) Locus – Is the attribute perceived by the individual as located "in" or "out of" him/her (such as skill and self-efficacy, attributes that are typically perceived as individual, personal, located "in" the student, versus difficulty of the task, which is typically perceived as an externally imposed condition, and therefore "out" of the learner)?

(b) Controllability – Is the attribute grasped as something one can control and manipulate (such as effort versus luck)? The locus of control is a combination of locus and controllability. For example, while I may accept that I control how much effort I exert, I may feel that I am being forced to exert effort rather than choosing to do so myself. The locus of control has been used in studies on wait time, problem solving, understanding of the nature of science, meaningful learning, and others.

(c) Stability – Is the attribute grasped as something constant or variable (such as fatigue or help from friends)? The more the attributes for success are perceived as internally located, controllable and stable, the greater will be the motivation to engage in a learning task.

Both expectancy-value theory and attribution theory focus on the magnitude of motivation for engaging in a learning task; while self-determination theory and achievement goals theory also attend with the effects of being more or less motivated, they also emphasize the qualitative nature of motivation, distinguishing between different types of motivation.

Self-determination theory emphasizes every person's need to belong, to feel able, and to be autonomous. It distinguishes between intrinsic motivation (doing something for its own sake) and extrinsic motivation (doing something because it leads to certain results). Research shows that highly intrinsically motivated people tend to be more adaptable and have better conceptual understanding than people with lower intrinsic motivation. Intrinsic motivation is supported by providing students with a sense of control and choice, challenges that lie within their zone of proximal development, positive feedback about their abilities, and close personal relations.

Achievement goal theory has been used more often in science education studies than the other motivational theories. It focuses on individuals' goal orientation, which is why individuals engage in learning activities. The theory distinguishes between two main goal orientations: mastery goals orientation and performance goals orientation. Mastery-oriented individuals strive to develop competence in order to achieve a sense of mastery; they learn because they want to understand. Mastery goals orientation is positively associated with a wide range of positive cognitive, emotional, and behavioral outcomes and should therefore be fostered by parents, teachers, and schools. Performance-oriented individuals strive to demonstrate competence and are therefore concerned with others' perceptions of their competence and with their ability relative to others. Performance goals are subdivided into performance-approach and performance-avoidance goals. According to this distinction, when pursuing performance-approach goals, individuals are focused on attaining favorable judgments of competence; they learn because they want others to think they understand. On the other hand, when pursuing performance-avoidance goals, individuals are focused on avoiding unfavorable judgments of competence; they are concerned that others may think that they don't understand. Findings from studies that have adopted this distinction between performance-approach goals and performance-avoidance goals support its prevalence among students and strongly suggest that performance-avoidance goals are associated with maladaptive patterns of engagement. On the other hand, the evidence regarding performance-approach goals is not consistent. People are not either mastery oriented or performance oriented. Mastery orientation and performance orientation are two independent continua characterizing individual learners. One can be both high mastery and performance oriented or be characterized by any two values of goal orientation on both continua.

Aspects of the Significance of Motivation in Learning Science

We have all learned things that we no longer remember; often we don't even remember that we ever learned these things! Knowledge that is not revisited, built on, used, and embellished is doomed to fade away. When we are faced with an issue, such as whether or not to consume genetically modified foods, in order to reach a position that is not just emotionally driven but also supported by reason, we need to be able to recall and draw upon concepts related to genetics, nutrition, and ecosystems that we learned in middle and high school. More likely is that whatever we learned in high school will not suffice to reach a firm understanding of the issues at stake in genetic engineering; so we will need to go beyond our school-based knowledge and learn new ideas. For this learning to occur, we need to be motivated to learn. Thus, the goal of helping people become lifelong learners is contingent on the existence of ongoing motivation to learn (Maehr 2012). The goal of education is not to fill a pail but to light a fire (sometimes attributed to Yeats).

Rather than feed the fire of motivation to learn science, many studies from the late 1960s and onward suggest that schools often do the opposite – they extinguish it. Six-year-old children are typically full of awe and curiosity about the world. Your average 14-year-old child, however, has lost his drive to understand and make sense of the world, he is no longer inquisitive. Research has not only documented students' declining motivation to learn science but has also shown that this waning of motivation to learn science is not an inevitable consequence of adolescence; schools and teachers can support and enhance students' motivation to engage with science or they can diminish it (Nolen 2003; Vedder-Weiss and Fortus 2012). Clearly this has great significance when considering the widespread phenomenon of declining student enrollments in science and how to reverse such trends. Understanding the reasons for this decline in the motivation to learn science and how to best address it should be one of the central goals of the science education community.

Cross-References

- ▶ Affect in Learning Science
- ▶ Attitudes to Science and to Learning Science
- ▶ Emotion and the Teaching and Learning of Science
- ▶ Interests in Science
- ▶ Self-Efficacy in Learning Science

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Multiculturalism

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Keywords

Culture; Diversity; Equity; Multicultural; Social justice

Multiculturalism

Multiculturalism has been used by scholars and practitioners from countries all over the world in referring to educational efforts to instruct and infuse more positive values about human pluralism and to improve the learning potential for all students. Multiculturalism is a philosophical position and movement that assumes that the gender, ethnic, racial, and cultural diversity of a pluralistic society should be reflected in all of its institutionalized structures but especially in educational institutions, including the staff, norms and values, curriculum, and student body. It recognizes that equality and equity are not the same thing, meaning that equal access does not necessarily guarantee fairness.

Within the United States, the origin of multiculturalism was more concerned with freedom, liberty, and equality and less with particular subcultures in society. However, over time, multiculturalism has evolved to focus on ethnic and cultural diversity, as well as cultural identity. Cultural identity is based on traits and values learned as part of our ethnic origin, religion, gender, age, socioeconomic level, primary language, geographical region, place of residence (e.g., rural, suburban, or urban), and disabilities or exceptional conditions. Each of these groups (also called microcultures, subsocieties, subcultures, subcommunities) has distinguishable cultural patterns shared with others who identify themselves as members of that particular group. Individuals belonging to the same microcultures or subcultures share traits and values that bind them together as a group. Although numerous microcultures exist within most nations, the United States is exceptionally rich in having very diverse and distinct cultural groups that make up its population and history. Individuals with competencies in several microcultures may be considered bicultural or multicultural or bilingual and multilingual. These individuals may develop a broader view and range of cultural competencies as a member of multiple microcultures (Grant and Ladson-Billings 1997).

Multicultural Education

Multicultural education grew out of two primary movements – the Civil Rights Movement of the 1960s and 1970s and the Ethnic Studies movement, which grew out of the Civil Rights Movement. During these movements, African Americans and many other groups of color demanded equity and equality in the policies and practices of schooling. Consequently, numerous schools developed and taught ethnic studies courses and colleges and universities established ethnic studies departments or programs. Also during the Civil Rights Movement, other groups (women, people with disabilities, the poor, and gays, lesbians, and bisexuals) began to increase their efforts to make schooling equal and equitable for members of their groups. In the 1970s, the multicultural education movement grew. The Civil Rights Movement and the Ethnic Studies movements were energized by scholarship and participation by groups of color, women, and people with disabilities, and soon the influence of these movements began to capture the attention of K-12 and university educators. From that time to the present day, multicultural education has developed to become the educational vision and approach to school and societal change that has been advocated by an increasing number of people, but also objected and challenged by others.

Multicultural education, sometimes referred to as multiethnic education, antiracist education, or multiracial education, has been used by countries around the world and thus widely used in the field of education. It is a philosophical concept and an educational process. Multicultural education as a philosophy and practice continued its early development as different groups (African American, Asian American, Latino, Native American, and European American) began to learn (both formally and informally) about how race, class, and gender influence their presence in society and in educational settings and how their group and other groups contributed to the growth, development, and history of the United States. As an educational process, multicultural education has many approaches that vary widely. Although there are many different approaches, leaders within the field of multiculturalism have reached some level of consensus on the goals, aims, and purpose of multicultural education (Banks 2001).

Goals of Multicultural Education

A major goal of multicultural education is to reform the school and other educational institutions so that students from diverse racial, ethnic, and social-class groups will experience educational equality (Banks 2001). Another important goal of multicultural education is to provide both male and female students an equal chance to experience educational success and mobility. Multicultural education theorists are increasingly interested in how the interaction of race, class, and gender influences education, yet the emphasis that is given to these variables varies greatly. Most multicultural scholars and researchers agree that institutional changes must occur if the goals of multicultural education are realized or implemented successfully. Institutional changes may reside in changes in the school curriculum; teaching materials; teaching and learning styles; the attitudes, perceptions, and behaviors of teachers and administrators; and the goals, norms, and culture of the school (Sleeter and Grant 2009). Therefore, multicultural education confronts social issues involving race, ethnicity, socioeconomic class, gender, sexual orientation, and disability. Multicultural education provides instruction in familiar contexts that are built upon students' diverse ways of thinking. It encourages students to investigate world and national events, as well as how these events affect their lives. It teaches critical thinking skills, as well as democratic decision making, social action, and empowerment skills.

Multicultural education theory, practice, and research are conceptually defined in several different ways, with a number of educators attempting to deal with this differentiation by developing typologies or approaches to multicultural education. These typologies and approaches also aid in defining the goals of multicultural education.

Banks (2001) describes five dimensions of multicultural education as *content integration*, *the knowledge construction process*, *prejudice reduction*, *an equity pedagogy*, and *empowering school and social structures*. Briefly, (a) *content integration* deals with the extent to which teachers use examples, data, and information from a variety of microcultures in illustrating basic educational concepts, principles, generalizations, and theories in their subject area or discipline; (b) *the knowledge construction process* describes the procedures by which social, behavioral, and natural scientists create knowledge and how the implicit cultural assumptions, frames of references, perspectives, and biases within a discipline influence the ways that knowledge is constructed within it; (c) *prejudice reduction* describes the characteristics of children's racial attitudes and strategies that can be used to help students develop more democratic attitudes and values; (d) an *equity pedagogy* exists when teachers use techniques and methods that facilitate the academic achievement of students from diverse racial, ethnic, and social-class backgrounds. Finally, (e) *empowering school and social structures* are designed to help students and teachers cross racial and ethnic boundaries so that students may participate more effectively in school and society. These five dimensions of multicultural education help students to develop positive self-concepts and identities as they learn about the culture, contributions, and history of diverse groups that have contributed to their nation's history.

Nieto frames a definition and goals of multicultural education within a sociopolitical context because multicultural education needs to confront issues of power and privilege in society and not just issues of difference (race, class, gender, etc.). Nieto and Bode (2008) focus on seven characteristics of multicultural education: *antiracist education*, *basic education*, *important for all students*, *pervasive*, *education for social justice*, *a process*, and *critical pedagogy*. First, (a) *antiracist education* makes antidiscrimination explicit in the curriculum and teaches students the skills to combat racism and other forms of oppression; (b) *basic education* advances the idea that all students have a right to engage in core academic subjects as well as the arts and to develop social and intellectual skills and knowledge to be used in a diverse society; (c) multicultural education is *important for all students* because it challenges the commonly held misunderstanding that it is only for students of color, multilingual students, or special interest groups; (d) the *pervasive* nature of multicultural education emphasizes an approach that permeates the entire educational experience, including school climate, physical environment, curriculum, and relationships; (e) *social justice* teachers and students put their learning into action, and students learn that they have the power to make a change in a democratic society; (f) as *a process*, multicultural education is an ongoing developmental process that involves relationship building among individuals and educational institutions; and (g) *critical pedagogy* draws upon experiences of students as well as multiple viewpoints that lead to self-reflection and action.

From a review of the literature, Sleeter and Grant (1985) observed five approaches to multicultural education. They are t*eaching the exceptional and the culturally different*, *human relations*, s*ingle- group studies*, *multicultural education*, and e*ducation that is multicultural and social reconstructionist*. Sleeter and Grant also acknowledged that there is some overlap between the five approaches that they outline. First, (a) *teaching the exceptional and the culturally different* aims to equip students with the academic skills, concepts, and values to function the American society as well as its culture and institutions; (b) *human relations* consists of developing positive relationships among diverse groups and individuals to fight stereotyping and to promote unity; (c) s*ingle-group studies* have a target group that is looked at in depth and information about the group's history, including experiences with oppression and resistance to that oppression, is highlighted; (d) *multicultural education* is used by Sleeter and Grant as an approach to include the previous approaches and to deal with multiple groups at the same time and to reform the total schooling process so that all students benefit from a multicultural education; thus, this approach focuses on issues and concerns across multiple groups (Banks 2001); and (e) e*ducation that is multicultural and social reconstructionist* describes a complete redesign and critical action toward social change. For example, it entails addressing issues and concerns that affect students of diverse groups and encourages students to take an active stance by challenging the status quo, speaking out, and joining with other groups in examining common or related concerns.

Multicultural Education Across Subjects

Multicultural education extends to all subject areas, including science and mathematics as well as social studies, language arts, and art. Multicultural education across different subjects teaches students to apply critical thinking skills to all subject areas. Moreover, multicultural teacher education practice and policy derives from work within subject areas, such as multicultural science teacher education (Atwater and Riley 1993), and prepares teachers to become multiculturalists in their approach to teaching and vision for education.

Scholars and practitioners new to multicultural education as a field may find that the existence of several different approaches to multicultural education may lead to conceptual confusion. This confusion suggests to some that multicultural education is inconsistent, making it the subject of criticism (see Grant and Ladson-Billings 1997 for discussion). The shortcoming of the multicultural approach is that it does not assertively address issues dealing with poverty and unemployment, nor does it necessarily help build the political skills and group solidarity that some ethnic groups need (Grant and Ladson-Billings 1997). However, as more researchers and teachers come to understand multiculturalism and multicultural education, and develop broader views in areas such as **sociocultural perspectives and gender**, the meanings of multiculturalism and multicultural education will become more defined, accepted, and affirmed as well as more refined in its definitions and approaches and its application across different subject areas. Therefore, teachers in each subject area can analyze their teaching style to determine the extent to which they reflect multicultural issues, values, and approaches.

Summary

Multiculturalism is a common feature of many countries in the Twenty-first Century. For some, such as USA, multiculturalism has been a central feature of their society for many years, for others, such as Australia (by many measures today the most multicultural country on the planet) this is a more recent – post World War Two – development. Multicultural education acknowledges and affirms the belief that the strength and richness of such countries is in their human diversity. It demands a school staff that is multiracial, multiculturally literate, and multilingual. It demands a teaching staff that reflects gender and race diversity across subject matter areas. It demands a **curriculum** that organizes concepts and content around the contributions, perspectives, and experiences of all the groups that are a part of US society and the greater world. It confronts current social issues involving race, socioeconomic status (SES), gender, sexuality, and disability. Multicultural education accomplishes this by providing instruction in a social-cultural context that students understand and are familiar with and builds upon students' learning styles and community strengths. It teaches critical thinking skills, as well as democratic decision making, social action, and empowerment skills. Finally, multicultural education is a total process – it cannot be truncated and trivialized. All the components of its definition must be in place for multicultural education to be genuine and viable.

Cross-References

- ▶ Cultural Influences on Science Education
- ▶ Cultural Values and Science Education
- ▶ Culture and Science Learning
- ▶ Curriculum
- ▶ Sociocultural Perspectives and Gender

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Multimedia Videos and Podcasting

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Keywords

Multimedia; Online video; Podcasts; Video clips

Main Text

Science educators have a long history of incorporating diverse media into classroom experiences. From the advent of educational television (ETV) in the 1950s to microcomputers in the 1980s to the current applications of smartphones and tablets for learning, multimedia videos have been one of the principle means of augmenting the quality of learning in science classrooms. The role that videos play in science instruction has changed dramatically, however, both as a result of changing views of teaching and learning and as a result of the hardware available to teachers.

Initially, educational television was thought of as a means of efficient of delivery of content and equity in school curriculum by ensuring that all children were able to watch high-quality content created by expert teachers (Cuban 1986). These early educational videos were thought of primarily in terms of the ability to transmit factually correct information. While some technology enthusiasts argued that ETV could replace teachers, most educators viewed television as a teaching aid to be used under certain conditions. Television was valued for its ability to depict dynamic scientific processes and remote locations. Most science classrooms have access to TVs, VCRs, and DVD players so that teachers can show videos (or clips of videos) deemed to have some educational value. The use of videocassettes and DVDs reflect the expectation that videos are best used "on demand" (i.e., rather than on scheduled broadcast) and that teachers must have flexibility to integrate them into their curriculum.

The World Wide Web (WWW) has introduced a vital new source of multimedia videos for use in science classrooms. Although the first decade of the public use of the WWW did not have sufficient infrastructure to make video streaming practical in most cases, the increased bandwidth and network service to schools, together with the proliferation of computers, have provided science teachers with a wealth of accessible digital video online. The popular video-sharing site YouTube, founded in early 2005, makes it easy for anyone to upload video clips for public viewing. Not only can science teachers view videos "on demand"; they can dynamically search for relevant video content from home, at school, or during an unplanned moment in class. For example, a science teacher might quickly call up a YouTube video that helps explain a concept in response to an unanticipated question during a classroom discussion. Importantly, students with access to the Internet at home are able to find the videos shown in class or search for additional video content to supplement their learning.

The high volume of multimedia videos, together with the highly accessible searching and viewing environments, can help students take more control over their learning, as ownership and control of video content no longer resides exclusively with teachers. New forms of digital devices, such as smartphones and tablet computers, have make accessing multimedia video content even easier. These devices routinely have built-in video cameras that enable both science teachers and students to create their own multimedia videos for pedagogical purposes.

The twenty-first century has thus seen a shift away from using multimedia videos solely for the purposes of transmission of scientific knowledge; learners can now use relatively inexpensive and common equipment to access, create, and co-construct knowledge about science. Such applications of multimedia videos are consistent with a social constructivist view of learning and fit well within the recent social phenomena of "Web 2.0" (i.e., where many users contribute to collections like YouTube or Wikipedia and all benefit from the aggregated resources). One example of using video to empower students to create knowledge about science is found in the Slowmation project, which challenges students and teachers to create models of scientific concepts (e.g., mitosis) and then take digital photos of their models and edit them into a short stop-motion animation film, complete with voice-over narration (Hoban 2007). In the classroom, a science teacher would facilitate the creation of student-produced Slowmation videos as a way for students to visualize and reflect upon their own ideas as well as to reveal the range of conceptual models that exist within the student community.

Around the same time the YouTube.com emerged, a journalist commenting on the new form of amateur radio on the Internet coined the term "podcasting" (Berry 2006). Podcasting is a portmanteau of the words "iPod" and "broadcast" – the former being the most popular (although by no means only) digital media player over the last decade. A podcast is a syndicated form of media – either audio, video, or textual – that is delivered over the Web. Users can "subscribe" to any podcast using popular software such as iTunes, or via a dedicated website, and listen to or view it using a computer, tablet, smartphone, portable gaming system, or dedicated media player. Podcasts have been called “a converged medium” because they bring together audio and video media, the Internet, and media devices (Berry 2006).

Although there are many professionally produced podcasts available from sites such as Scientific American (e.g., http://www.scientificamerican.com/multimedia.cfm) and the Canadian Broadcasting Corporation (CBC, e.g., http://www.cbc.ca/quirks/), one of the hallmarks of podcasting is the vast array of contributions made by amateurs who simply wish to create and broadcast their own content. Almost any current computer system has the necessary hardware and software to create a podcast, and a variety of free solutions are available for uploading and “hosting” the podcasts. Thus, the barrier to creating and distributing podcasts is low, suggesting possible applications for K12 or higher education. For example, a science teacher might use the Science Talk podcast from Scientific American in the same way that she/he might have used an educational television program in the past – to provide enriched multimedia content to students. Alternatively, a science teacher might challenge students to create their own science podcasts in small groups around a particular topic or theme. Podcasts and digital video clips, because of their ubiquity and ease of creation, editing, and publication, offer exciting new possibilities for science educators to find ways to encourage their students to construct knowledge of science.

Cross-References

▶ Broadcast Media
▶ Online Media

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Multimodal Representations and Science Learning

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What Is Meant by Multimodal Representations?

The rising science education interest in multimodal representations reflects science educators’ drive to get to the heart of knowledge generation and change, as close to the causal link between students’ not knowing and coming to understand as it is possible to get. “Multimodality” is beginning to define a discrete field of research, though, as it is still in relative infancy, it is in need of being more fully articulated. The general definition of multimodal representations used in this entry is “the depiction or communication of an idea or ideas using more than a single expressive mode, either in synchrony or separately.” Because education has traditionally been so strongly mediated by written and spoken language, an important aspect of this definition is that it is inclusive of all forms of expression, beyond only the linguistic. The definition of “representation” is more ambiguous as the term may be used to refer to both “internal representations” (the existence of which some would contest) and “external representations.” While the use of the one word for both internal and external states is essentially ubiquitous, it is not helpful, but in both instances, the intention is to refer to something “re-presented” or “revealed in another manner,” in a form that differs from that of the referent. Any serious analysis of multimodal representations is drawn into a consideration of its underpinnings in cognitive and brain science as well as philosophy. In those disciplines, the difficulty of dealing with epistemology and consciousness has long been recognized, making an unequivocally clear steer for educationalists' application an unrealistic expectation. However, such a fundamental problem shared across disciplines is helpful in highlighting difficulties to avoid as well as positive ideas to pursue.

Whether in spite of or because of the nonlinguistic comprehensiveness of the definition of multimodal representations, among the frontrunners exploring this new territory are educators specializing in applications to the language arts. The obvious multiple modes to which these educators attend include expressive language (oracy, text) and receptive language (listening, reading), supplemented by the range of modes that add information to the genres of drama, poetry, literature, and language acquisition: gesture, images, nonverbal sounds, facial expressions, and so forth. These modes may arise independently and in combination, sometimes dovetailing complementarily, at other times offering a richness through redundancy of information. "Social semiotics" explicates the multimodal expressions that communicate meanings using such combinations of linguistic and nonlinguistic sign systems. Semioticians will claim, entirely plausibly, that it is only when the full complexity of the multimodal signs and processes being used are analyzed that the nuances of communicated information may be fully comprehended. Semiotic deconstruction of this nature has been applied to the analysis of science teachers' classroom communications. Arguably, such communicative performances are but one step away from rhetoric, in the sense of being shaped by an intent to present information to persuade, or at least, with a clarity that conveys conviction and optimizes accessibility for the recipient.

The commercial and academic interest of the advertising, marketing, and entertainment industries in multimodality is also easy to understand, with "multimedia" and "multimodality" sharing common ground in the potential to exploit a range of communicative possibilities to inform and persuade. Indeed, Marshall McLuhan's still widely quoted declaration that "The medium is the message" can be seen as a herald of current interest. Computer scientists are also significant stakeholders, in both modeling the cognitive processes and exploiting the multimedia potential.

Science educators and learners have access to an extensive array of information communication modes, far beyond language enriched by gesture. Science education can exploit the full range of human sensory systems and use instrumentation to extend the detection of the entire electromagnetic spectrum. In addition, various formats and systems have been invented for quantifying data. A huge selection of possible multimodal representations is used habitually in science: text; images; cross-sectional and labeled diagrams; 3D models and specimens; mathematical, graphical, pictorial images and photographs; chemical symbols and equations; video and audio recordings; magnified images; waveforms; and many more formats. All can be described at a simple level in terms of the basic sensory channels by which they are accessed, with layers of complexity added when used symbolically. What evidence is available to support an informed analysis and management of multimodality, such that claims that it can help to make a difference to teaching and learning processes and outcomes might be tested? Does the modality of a representation make a difference to an individual's performance as a learner addressing a problem or faced with acquiring a new understanding through engaging in some form of conceptual change process? Or from the instructional side of the process, what difference might views about multimodality make that will be of benefit to teaching? An encouraging illustration of representational modes making a difference to performance is found in U-shaped growth, the interpretation of which has a bearing on this discussion.

U-Shaped Behavioral Growth

U-shaped behavioral growth is a phenomenon that has been debated in child development literature for decades and which continues to be reported in various manifestations. This form of growth has usually been described in cross-sectional samples by age, where the correct solution to a problem is achieved by a younger age group, drops out in a middle group by age, and reappears in the behavior of older subjects in the sample. The domains in which this developmental pattern of correct-incorrect-correct outcome is recorded are varied; the age ranges typically span something like 4–12 years. The theoretical relevance to a discussion of multimodality resides in the interpretation of the subjects' underlying reasoning. The favored interpretation is that two representational formats are being used, with the attempted deployment but incomplete mastery of a more advanced format resulting in a temporary decline in performance. This can be illustrated by reference to the understanding of transformations associated with intensive physical properties.

An intensive property does not change with changes in its extensive property. Temperature is an example: volumes of water at a given temperature may be mixed (changed in extent) but the resulting temperature remains the same. Strength or "sweetness" of solution is another intensive property. When volumes of liquid of the same concentration are added together, the ratio of solute to solvent remains constant even as the extensive property is increased.

When presented with the combination of two volumes at the same temperature or of identical sweetness, younger children (around 4 years) predict correctly no change in the resultant sweetness or temperature, as do older subjects (around 12). However, those approximately in the middle of the 4–12 age range tend to predict an increase in temperature or sweetness. It is the interpretation of this kind of error that illuminates the potential impact of multimodal representations. The inference, based on qualitative interview responses, is that two separate representational systems are being deployed. While the younger respondents are referring to an intuitive representation of temperature and sweetness, those in the mid range, with the correct intention, are attempting to use a mathematical or quantitative representation of the problem. However, they are failing to deal with what is a ratio problem, perhaps because they focus on the numerator rather than the proportion. Their prediction is incorrect until such time as the two representations – the temperature/sweetness and the ratio – are consolidated to generate a consistent outcome. An important aspect of the theoretical perspective on this interpretation is that the correct-incorrect-correct behavioral sequence can be thought of as a positive incremental conceptual progress, though it is masked by a behavioral setback. The generalization drawn is that it helps to have some interpretation of what representations are guiding thinking inside students' heads if we wish to manage multimodal representations positively.

The Structure of the Brain and the Structures of Thinking

Knowledge of the structure and organization of the human brain has increased rapidly in recent years but remains one of the outstanding major frontiers of science. Historically, there was a belief that bumps and irregularities discernible on the skull's outer surface might provide clues about the differentiated activity driven from within the carapace. When hypothesized correlations between externally measured features of the cranium and subjects' behavioral and emotional life failed to convince, interest in such approaches withered. However this left some interesting legacies, one such being the idea of human psychology being differentiated and structurally localized, as assumed in faculty psychology. Localized damage may result in specific impairments of psychological functioning, as brain trauma incurred in combat, strokes, and accidents confirms. For example, damage to the right cortex is associated with motor impairment, to the left with language degradation, yet healing often involves compensatory effects, suggestive of an interconnected or holistic brain functioning. The specific and the general view of brain functioning must both be acknowledged and accommodated in explorations of multimodality.

Is Intellectual Functioning Domain Specific or Domain General?

A view of the brain as a general-purpose problem-solving organ, fully interconnected for internal communication of data, might lead to a different view of multimodal representations as compared with an assumption of modularity. Is intellectual behavior better thought of as domain general (interconnected and homogeneous) or domain specific (modular, dealing in an array of restricted, relatively narrow classes of object and properties)? In the latter part of the twentieth century, it was suggested that some structural predisposition was needed to explain the enormously complex language development achieved so rapidly by very young children and the notion of the functioning of the brain as modular gained prominence. Modules for face recognition (another precociously developed human skill) and for the "theory of mind" (the attribution of mental states of knowing to others) have also been suggested as modules. Such domain-specific capabilities at the starting point of development are assumed by some to be distinct and discrete rather than generalizable to all learning.

Ideas About Modularity of Mind

Jerry Fodor, a prominent philosopher and cognitive scientist, suggested in the 1980s that some psychological processes occur as modules, discretely packaged entities. He proposes a three-tier organization: (i) a transducer process that transforms environmental signals into a form usable by "the system," (ii) an input process that recognizes and organizes those transformed signals in different formats or "modes," and (iii) higher-level cognitive functions performed on those inputs. Modules are defined by several particular characteristics, including automaticity and being encapsulated: they are separate from one another and from the third level. Conscious operations across modules are defined as possible only at the third level, where "the system" makes decisions and acts on the basis of all the domains of information from the input structures to which it has access. Only at the third level is there conscious management and the possibility of modules "interfacing" or "talking to one another."

Fodor's formulation offers one way of making sense of the U-shaped growth curves described earlier. Consider again the temperature and sweetness examples used above. The system may have a representation of the taste of sweetness and the feeling of temperature, as well as spatial representations of volume and a mathematical representation of ratio. These must be consciously coordinated to generate a correct prediction to an intensivity problem.

There are other complexities around the notion of modularity. Firstly, Fodor's expression of modularity is known as "modest," in contrast to more recent suggestions by evolutionary psychologists of "massive" modularity, with the proposal that all modules, including higher-level conscious operations, are function specific. This "massive modularity" hypothesis will not be discussed further here. More important is the recognition that those who argue for Fodor-style modules are adopting a nativist position that assumes developmentally predetermined modules. The nativist views of modularity described above are radically and fundamentally challenged by a developmental perspective that insists on a greater attention to the role of epigenesis in cognition.

Modularization as an Epigenetic Process

Epigenetics is a growing field of study, stimulated by recent knowledge about the human genome. Exploration of the environmental variables associated with the expression of very specific genetic factors is made possible, genes being assumed to offer a potential that is realized in a dynamic union with environmental experiences. These kinds of enquiry challenge the paradigm of genetic determinism. They have their counterpart in neurodevelopmental studies that explore the cognitive correlates of genetically linked conditions having an impact on intellectual development (e.g., Williams syndrome and autism). The conclusion, as expounded by Karmiloff-Smith, is that modularization is a progressive process that can only be fully understood from a perspective that assumes very significant developmental plasticity. Neuroconstructivists point to evidence that some forms of environmental interaction over the time of a learner's development give rise to specializations in processing in particular domains.

Developmental and Micro-Developmental Change

Karmiloff-Smith's position is to expect uneven cognitive profiles, consistent with modularity and domain specificity rather than the nativist assumptions of unitary capacity. Environmental interaction over the time of a learner's development gives rise to specializations in processing; genes offer a potential, realized in dynamic conjunction with experiences during ontogenesis, resulting in modularization. Micro-developmental conceptual change follows a pattern involving three recurrent phases. In the first phase, the system's focus is on data arising from interaction with the environment and this phase persists until behavioral mastery. The second phase describes the internal dynamics of the system. In the third phase, with internal mental computations more stable, what Karmiloff describes as a process of "representational redescription" (RR) occurs. That is, the system reflects on what it knows as a new representation emerges.

An interesting contribution from brain imaging technology adds an empirical perspective to the narrative. Functional magnetic resonance imaging (fMRI), combined with a computational model, has been used to link neural activity (blood oxygen flow) to subjects' thinking about word-image instances of concrete nouns. The resulting "brain pictures" manifest characteristic patterns linked to specific word-images, distributed across three to five locations in the brain. Factor analysis of the outputs gave rise to three main semantic factors for physical objects that were reified as "shelter," "manipulation," "eating," and a fourth factor, "word length." Furthermore, similarities in the patterns for the same words generated by different subjects were identified as similar "brain pictures" across the sample. There may thus be some support for a form of localization of function in this work.

Review and Reflection

Figure 1 suggests a summary of the discussion above.

J.J. Gibson used the term "affordances" to describe action possibilities latent in the environment, constrained by the limits of an agent's repertoire of possible activities: this formulation applies equally to humans, to other animals, and to computers as intelligent machines. Affordances are regarded as latent in the environment and measurable; brain-body-environment permutations afford and limit possibilities for activity. An adaptive and evolutionary perspective suggests that the sense organs must be integral with perceptual systems to allow sense making, whereby values, possibilities, and meaning (e.g., "looks good to eat") are directly perceived. Gibson's formulation seems not inconsistent with the notion of modularity.

There are challenges to understanding in the processes indicated in Fig. 1, particularly between categories 3 and 4, the step across from neural physical correlates to mental events. Computer scientists might describe the process as analogous to binary code being translated to ASCII format. Neuroscientists point to basic neural processes including the growth of protrusions in the dendrites that carry the estimated one hundred thousand billion synapses and the transfer of proteins that, it is believed, play a critical mediating role in learning. Roger Penrose offers a quite different speculation that the wave-particle duality of quantum theory could have value in explaining consciousness, challenging the classical physicalism of reductionists and computationalists. The inescapable fact for science educators is that, however much is learned about physical brain processes, there is a chasm

1	2	3	4	5
EXTERNAL	INTERNAL			EXTERNAL
	PRE-CONSCIOUS		CONSCIOUS	
A range of energy forms in the environment is available for transfer from objects and events. Environmental affordances link environment, brain and body.	Energy from external sources impinges on sense receptors in human physical systems.	Brain inputs from receptors are translated into cognitively useable form, with modularisation and pre-conscious processing	Mental activities are involved in meaning creation (‘internal representations’).	Meanings are articulated using a range of formats, communicated externally to the environment as notations (‘external representations’)

Multimodal Representations and Science Learning, Fig. 1 Processes in the formation of representations

in our understanding of the link between the physical and mental events in the brain. The physical and mental descriptions are explanatory categories of two different orders that do not translate one to the other. It is in categories 4 and 5 of Fig. 1 that productive research and development in science education becomes a realistic enterprise.

Implications for Research, Development, and Pedagogy

Cautions: Some theoretical formulations are inconsistent with the arguments as set out above. For example, the theory of multiple but distinct intelligences, suggesting as it does that individual learners have different qualities of mind, is not consistent with the interpretations of multimodal representations discussed here. In its favor, the theory of multiple intelligences redresses the exaggerated weighting that education has traditionally bestowed upon linguistic modes. While the proposition that learners may favor different modalities at different times and in different circumstances is reasonable, to label some students as limited to particular qualities of learning as learning style adherents have advocated could be doing students a great disservice. Multimodality suggests that instruction should sample a rich variety of representational modes to offer all students. To limit individual learners to adopting constrained modes of learning is unacceptable once we accept that all learners with intact nervous systems have access to the same range of multimodality. Individual students might favor particular expressive modes, but these are more likely to be attributable to their sociocultural histories than inherent limitations.

Modularization and culture: Modularization of thinking implies that certain domains are likely to become prevalent in an individual’s thinking, operate faster, and perhaps to some extent become more automatic. Students’ habitual modes of thinking in modern societies are likely to be different from former times when the ubiquity of text, literacy, and quantification of most aspects of our current world and our experience of it were absent. In recent decades, the advent of digital media has been revolutionary for mental life and may account for the ontogenetic emergence of a changed quality in the nature of intelligence. This is one possible interpretation of a fall over a 30-year period in the level of intellectual functioning on a Piagetian task as measured by Michael Shayer and colleagues. Certainly, many twenty-first century students have access and are exposed to a range of multimedia digital representations beyond the imaginations of earlier generations. Such students are likely to be highly motivated by opportunities to express their understanding in ways familiar from the converging media of broadcast television and the Internet. Another perspective on a possible changing quality of mental life is that other activity-initiated representational possibilities might be closed down by increasingly sedentary lifestyles. Some evolutionists suggest that a critical period of motor activity is characteristically essential in mammalian development but is being missed or neglected in favor of digital lifestyle options. On the positive side, science educators are constantly confronted with problems as to how to represent inaccessible concepts that might be rarely occurring, dangerous, or at the extremes of scale. Modern multimedia enriches the range of representational possibilities and needs to be exploited in such circumstances.

Translation and triangulation of multimodal representations: A defining feature of external representations is that any single form can only ever approximate to that which is represented: some features will map propitiously, others less well. Metacognition is acknowledged by educationalists as important in meaningful learning, and the generative meaning-creation behavior required in category 4 requires hard brainwork. The meanings carried by representations cannot be assumed to be self-evident or made sense of by rote. Whether called "representational redescription" or "metarepresentation," the internal generative experience is one of the conscious explicitations, an act of fixing meaning and belief from inchoate to developed form. Cognitive activity fills in the gaps as part of the sense-making process between subliminal and conscious mental operations. Thoughts may need to be articulated externally in diagrams, speech, writing, or some other form in order to be fully realized, but often, the expression does not emerge as intended. While verbal learning is a common shortcut, it may lack the underlying domain-specific firsthand experience of meaning making that is accessed via direct experience.

There are occasions when it is important for science educators to bear in mind that multimodality implies very much more than different wrappings for the identical informational package. Assessment is one such context. Laboratory-based activities in science are highly valued but relatively expensive in management, time, and resources. It would be a cost-effective proposition to dilute laboratory and practical experience with other forms of thoughtful representational activity, both in teaching and in assessment. Such pragmatic management decisions should not be dismissed out of hand on the grounds of nonequivalence. The selected modality makes a difference, and switching modalities, for whatever reason, requires careful empirical consideration of the effects of such changes. For example, there do not seem to be any grounds for categorical assertions on either side that practical work in science can or cannot be assessed by other than practical means.

Drawing on representations from different modalities is intended to facilitate sense making by triangulating, and thus reinforcing, understanding. Students can be encouraged to reflect on the value of different versions or formats, critically scrutinizing the mapping between them. This critical activity is advocated as an explicit, external, and self-aware metacognitive activity. It is recommended as a strategy for accessing the conventional formats used in science teaching, giving students a more nuanced consideration of what is "real." This case-by-case approach to standard representations supports thinking and mediates learning. Since meaning making is such a personal activity, handing over ownership to students, rather than attempting to impose a rigid representational orthodoxy, offers them the opportunity to take creative responsibility for their own learning.

Another pedagogical perspective takes a broader view, from individual cases to the strategic place of representations per se in scientific endeavor. The argument here is that students can be encouraged to consider, from an overarching perspective, the role and value of representational forms and the purpose they serve as used by scientists. This broader perspective, labeled "metarepresentational competence" (MRC), is important in adding a reflexive dimension which helps to bring students' own awareness of their science learning procedurally closer to the way professional scientists operate.

Cross-References

- ▶ Constructivism
- ▶ Neuroscience and Learning
- ▶ Scientific Visualizations
- ▶ Visualization and the Learning of Science

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Multiple Intelligences

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Multiple Intelligences

The theory of multiple intelligences is predominantly attributed to the work of noted psychologist Howard Gardner during the late 1970s and early 1980s. Gardner conceived intelligence as having multiple rather than singular forms and developed a set of criteria for identifying unique intelligences, which included:

- It should be seen in relative isolation in prodigies, autistic savants, stroke victims, or other exceptional populations.
- It should have a distinct neural representation, such that its neural structure and functioning should be distinguishable from other human faculties.
- It should have a distinct developmental trajectory; different intelligences should develop at different rates along distinctive paths.
- It should have some basis in evolutionary biology.
- It should be susceptible to capture in symbol systems.
- It should be supported by evidence from psychometric tests of intelligence.
- It should be distinguishable from other intelligences through experimental psychological testing.
- There should be identifiable mental processes that handle information related to each intelligence (Davis et al. 2011).

Gardner initially identified seven intelligences that he developed as a theory of multiple intelligences and later, using the above criteria, Gardner added an eighth intelligence as described in the table below (Table 1).

Given Gardner's understanding of intelligence of being pluralistic, it is not surprising that his theory of multiple intelligences included the notion that each individual has a profile that includes all eight intelligences at various levels of strength and weakness. However it is incorrect to say that an individual would demonstrate no ability in a particular intelligence or that everyone would be classed as gifted in at least one intelligence. In fact Gardner makes only two primary claims:

- All individuals possess the full range of intelligences.
- No two individuals, not even identical twins, exhibit precisely the same profile of intellectual strengths and weaknesses (Davis et al. 2011, p. 492).

Gardner has continued to research his theory of multiple intelligences and believes he has

Multiple Intelligences, Table 1 Description of eight multiple intelligences

Intelligence	Description
Linguistic	An ability to analyze information and create products involving oral and written language such as speeches, books, and memos
Logical-mathematical	An ability to develop equations and proofs, make calculations, and solve abstract problems
Spatial	An ability to recognize and manipulate large-scale and fine-grained spatial images
Musical	An ability to produce, remember, and make meaning of different patterns of sound
Bodily-kinesthetic	An ability to use one's body to create products or solve problems
Interpersonal	An ability to recognize and understand other people's moods, desires, motivations, and intentions
Intrapersonal	An ability to recognize and understand his or her own moods, desires, motivations, and intentions
Naturalistic	An ability to identify and distinguish among different types of plants, animals, and weather formations that are found in the natural world

(Gardner 1993, 2011; Davis et al. 2011)

"suggestive evidence. . . for a possible existential intelligence ("The intelligence of big questions")" (Gardner 2011, p. xiv).

Multiple Intelligences in the Classroom

The educational implications of the theory of multiple intelligences has been summed up by Gardner, "an educator convinced of the relevance of multiple intelligence theory should 'individualize' and 'pluralize.'" By "individualize," Gardner means that an educator should know the intelligence profile of each student in their class so well that they are able to make adjustments to the teaching and assessment that are used. By "pluralize" Gardner means giving consideration to the topics or concepts that are most important and ensuring that they are presented through multiple modes of delivery, while at the same time highlighting the importance of the multiple modes of delivery as a way of considering what it means to understand something well.

Cross-References

- ▶ Constructivism: Critiques
- ▶ Didactical Contract and the Teaching and Learning of Science
- ▶ Representations in Science

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Museums

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In science museums you may find iconic artifacts like parts of Watson and Crick's original model of DNA; significant objects like fossils; a series of objects, artifacts, or models illustrating a developmental process or concept; dioramas of all sorts; singular chronological displays; taxonomic interpretations of the natural world; classification displays ranging from minerals to jet engines; explanatory graphics and computer games; and so on. Permanent exhibitions provide well-researched, detailed communications rather than accounts of the latest discoveries which may well be presented in temporary exhibitions. Museums are saturated with objects and the words interpreting them. The eclectic mix is part of their charm.

All museums are, like many scientific activities, expressions of fundamental human cognition patterns and psychological behaviors. Think about curiosity, delight in novelty and the unique, linguistic pleasure in naming and categorizing, love of collecting, delight in observation and measuring, brain and hand-eye coordination allowing the making of incredibly fiddly things, spatial intelligence prompting us to be imaginers of monumental manufacture, appreciation of the natural world, ties to home territories, and respect for the well-made object, or well thought out theory, which leads to aesthetic appreciation. Museums are cultural institutions reflecting varied expressions of natural tendencies.

Communication Research in Museums

Museum exhibitions are a form of 3D media which people walk through in a public, comfortable, and usually publicly funded space. They generally have a long life, maybe up to 30 years or more (recently a 100-year-old exhibition was replaced in a London national museum). Because exhibitions change at such an exceptionally slow pace compared to other forms of modern media, they are seen as an attractive, easy area for research and commentary by academics from emerging or developing fields such as media studies, cultural studies, anthropology, sociology, ethnology, political policy, development studies, and space syntax, along with other computing-based applications. Therefore, much of the critical writing on museums is written from a singular, academic point of view and fails to take account of museum histories, their conservative nature, the time scales to which they work, their restrictive budgets, their concrete communicative style, and their public popularity (McManus 2011).

Critical views have also been expressed by science museum curators who question the impression of the inevitable progress of science inherent in chronologically ordered displays. Within the museum profession there is discussion about communicating the social implications of technological developments, the problematic nature of science as a cultural activity, and how communications can be biased by the social and academic backgrounds of museum people. There is also a vibrant field of museological writing devoted to museum communication, audience studies, evaluation methodologies, and museum management, in which a fashionable tendency to adopt learning theories long after they have been abandoned by formal educationalists is evident. Current relativist interest in learning style theory and constructivism is seen by some as an excuse for inadequate conceptualization and preparation of communications for a general audience.

Museums in Their Historical Contexts

In all cultures, there have probably always been treasuries of objects with religious and kingly significance. Museum institutions are European products of the seventeenth and eighteenth centuries of the Age of Enlightenment. They have spread around the world as a result of colonization, twentieth century globalization, and, recently, as a result of development policies and the rise of mass tourism destinations.

Collections are the foundation of museums and the exhibitions about them may seem timeless. As a result, museum presentations vary according to their institutional histories, so large national science museums often offer a palimpsest of past scientific and technological preoccupations (McManus 1992).

The ancestral form of the museum is the Cabinet of Curiosities created during the Enlightenment in small rooms and galleries in the houses of wealthy men. Here they could show and discuss with their friends interesting rarities, specimens, ethnographic materials, scientific instruments, coins, and antiquities.

Older public museums are derived from subject matter breakdowns of the Cabinet of Curiosities collections. For example, the Ashmolean Museum, Oxford, Britain's first public museum, was founded in 1683 from the collections of John Tradescant, while the British Museum, London, was founded in 1753 from the collections of Hans Sloane. The "consumer characteristics" of such museums were, and sometimes still are, object saturation and authoritatively delivered information. In them, the curators privately researched the collections in tenured academic style, while the public activity of education and interpretation was undertaken by hired guides, educators, or designers. This historic split in status is mirrored in the institutional culture of many museums today.

In the 1960s and 1970s, there was an increasing desire to alter the focus of displays in the older science museums from a taxonomic display of objects to the presentation of explanations of interdisciplinary scientific ideas and concepts such as evolution, ecology, and atomic power. Gradually, a new approach to the visiting public, often based on mainstream educational theory, produced exhibitions with carefully structured information and engaging displays with which people could interact. Under these developments the educational function of museums came to the fore, and new museum professions came to include evaluators and researchers into learning in informal museum environments. The curator became subject matter expert rather than the initiator of exhibitions.

In the early nineteenth century, collections-based museums, discussed above, were slowly joined by science and technology museums concerned with training, the world of work, and scientific advance. Originally these were established to meet the practical needs of industry. For example, the V&A, London, was founded to promote design training. Mid-century, such pragmatic objectives, were rapidly overtaken by influences from a spate of popular trade exhibitions and world fairs. The fusion of the training-orientated, serious technology museum and the popular industrial exhibition with its beam engines and willingness to allow enjoyment gave rise to our familiar science and technology museums.

Around the mid-nineteenth century, there was also a rise in the foundation of provincial public museums which sought to provide sources of liberal education in an age without compulsory schooling. From the mid-nineteenth century up to today, the museum audience in general has become less academic or educated middle class and more general in character. However, it remains the case that an individual's level of education is the strongest indicator of the likelihood of museum attendance.

In recent times, museums devoted to the transmission of scientific ideas and concepts, rather than the building of collections and scholarly research into them, have arisen. Their primary objective is public education and they are often offshoots from educational institutions. Such museums tend to present thematic exhibitions of current contemporary significance and to contain interactive exhibits. Nowadays, themes could include heredity, sustainability, global warming, and so on. Examples of such museums are Palais de la Decouverte, Paris (1937), New York Hall of Science (1964), Lawrence Hall of Science (1968), and the Exploratorium, San Francisco (1969). Science centers could be said to be decontextualized scatterings of interactive devices first pioneered in this range of modern public education museums.

Differences Between Formal and Informal Education

Museums are prime examples of informal educational environments, so it is important for museum people to conceptualize a philosophy of informal education and to avoid mimicry of the attitudes, teaching style, and methods of schools and colleges.

In formal educational situations, where you will learn, who you will learn with, whether you are qualified to learn, who you will learn from, what you will learn, how long you will be given to learn it, and agreement on what you have learned and your level of understanding are matters largely out of control of the individual learner. As a result of these restrictions on the individual, formal institutions are very efficient, admirable means of communicating knowledge throughout societies for the benefit of those societies and the individuals within them. Formal education has developed a pedagogy which, some say, applies to a somewhat restricted range of human learning mechanisms and behaviors. Distinctive forms of evaluation have been developed to assess learning under these enhanced, prescribed conditions.

Most museums have an educational remit built into their trustee documents, but efforts to measure learning in the museum environment using methods from the formal education sector have failed. Here lies a fundamental difference between the two sources of knowledge and understanding. Informal education is entirely free choice in every way and is largely a leisure activity. As far as museums are concerned, people can choose to visit when they feel like it and age or level of experience are not barriers – all are welcome. Museum visitors can attend to exhibits within exhibitions for as long or short a time as they wish, or they can walk straight past them. Since museum visitors arrive with widely different levels of understanding, personal expectations, and differing social contexts (families, friends, or alone), museum professionals must constantly deal with multiple audiences for their communications. Accordingly, useful museum evaluations are concerned with investigations into conditions which would support learning in the motivated enquiries about what sense people make of their experiences, and descriptions of visitor behavior (which can be quite consistent across all museum types). In recent years, public-facing museums have come to understand the differing segments of their increasingly well-educated audiences. Science learning is strongly supported in science museums because most museum evaluation methodologies have been developed in them.

Other sources of informal education include television and radio science programs, science sections in newspapers and magazines, botanical gardens, zoos, nature reserves, archeological sites, and historic houses. The intention to inform during “worthwhile” leisure time unites them all.

Out-of-School Museum Impacts

All types of museum collection can be splendid, rich places for anyone to find out about scientific concepts, processes, and technical applications. However, museums vary and are often very individualistic institutions. Those wishing to use them to teach out of school may have to adopt a lateral thinking approach to tailoring communications and really get to know their local museum. For example, at the Institute of Education, London, beginning mathematics teachers are taken to visit the nearby British Museum to work with Sumerian clay calendar tablets. At another museum, an education section may offer an “off the shelf program” which will just suit curricular needs. Some museums will offer educators Web-based materials, but because the essence of museum use is witness of primary evidence and the sight of “real things”, visits are best, if possible.. A well-planned school visit to any museum will involve a teacher who knows the institution they wish to visit and will not panic about losing control when out of classroom, preparation teaching about the planned experience, quick settling down of excited children in a novel environment, and the allowance of lots of free-choice activity after the planned topic has been dealt with along with follow-up at school afterward. It is important that the informal educational dimensions of museums are catered for.

It is known that children may pester their parents for a return visit to the museum after a school visit. This is especially if they have been taken out of their normal, everyday environment so that they have glimpses of a bigger, more varied social and natural world and have become curious about it. Such visits can leave people with long-lasting visual and episodic memories. Such powerful impacts are reasonable typical outcomes of visits to intentionally educational environments open to the general public (McManus 1994).

Cross-References

- ► Excursions
- ► Explainer
- ► Learning Science in Informal Contexts
- ► Science Exhibits
- ► Visitor Studies

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National Assessment of Educational Progress (NAEP)

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The National Assessment of Educational Progress (NAEP) is the national measure of what students in the United States know and can do across multiple grades and ages in a variety of academic subjects. The NAEP program includes two components: long-term trend (LTT), an age-based national assessment (ages 9, 13, and 17) that has been conducted since 1969, and main NAEP, a grade-based assessment (grades 4, 8, and 12) begun in the late 1980s that reports trends in student achievement at the national and state level, as well as for select urban districts. Main NAEP assesses students at the national level in reading, mathematics, science, writing, economics, US history, civics, geography, the arts, and most recently in technology and engineering literacy. State- and district-level assessments are conducted in reading, mathematics, writing, and science at grades 4 and 8. Recent state-level assessments also have been conducted at grade 12 in mathematics and reading. Currently, LTT NAEP only assesses students in reading and mathematics, although science and writing were also assessed until the late 1990s.

The National Assessment Governing Board was created by congress in 1988 to set policy for NAEP. The Governing Board is an independent body of diverse members, appointed by the Secretary of Education, with representatives from government and public policy, education, and the general public who reflect a range of perspectives and interests. The Governing Board is responsible for selecting which subjects and grades will be assessed each year, developing the assessment frameworks, setting the Achievement Levels, approving all assessment content, and publicly releasing NAEP reports.

NAEP is administered by the National Center for Education Statistics (NCES), part of the Institute of Education Sciences (IES) in the US Department of Education. NCES oversees the NAEP Alliance, a joint body of contractors who develop, administer, process, score, and prepare reports of the results from the various assessments. For main NAEP, the core subjects (mathematics, reading, writing, and science) are assessed on a regular basis. Since 2001, assessments at grades 4 and 8 in reading and mathematics are given every 2 years. Assessments in science and writing at all three grades and mathematics and reading at grade 12 are conducted approximately every 4 years. Other subjects are assessed periodically, depending on the budget and priorities set by the Governing Board. LTT assessments in reading and mathematics are conducted every 4 years.

Along with providing current information on what students know and can do, a primary

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purpose of NAEP is to monitor trends, or how student performance has changed over time. The assessments have been designed to allow comparisons of student performance over time and among subgroups of students according to gender, race/ethnicity, socioeconomic status (SES), students with disabilities (SD), English language learners (ELL), and region, as well as other demographics.

For all main NAEP subjects, the Governing Board has developed assessment frameworks, which provide guidance on the content to be assessed, the types of questions, and the administration of the assessment. These frameworks are typically in place for 10–12 years in order to report trends but undergo revision periodically to ensure the assessment stays current with developments in the field and in curricula and assessment. Depending on the extent of framework revisions, a new trend line may be established or a special trend study conducted to compare student performance based on the old and new frameworks. LTT assessments are based on older frameworks that are essentially unchanged since the 1980s.

NAEP assessments also include questionnaires to collect contextual data from students, teachers, and schools, including student characteristics such as race/ethnicity and parental education, classroom practices, teacher characteristics, and school resources and environments. Each student sampled takes a 10–15-min questionnaire as part of the assessment. In addition, questionnaires are administered to the teachers of the sampled students at grades 4 and 8 and to school administrators. NAEP questionnaires are updated periodically and are available to the general public for various subjects, grades, and assessment years (http://nces.ed.gov/nationsreportcard/bgquest.asp).

NAEP assessment development is a multistep process that typically requires about 2–3 years and includes reviews by multiple stakeholders. For each assessment, a large pool of items (test questions) is developed based on the assessment framework. All items undergo content, technical, and editorial reviews for accuracy, framework alignment, and grade-level appropriateness, as well as for potential bias. Reviews are conducted by the test development contractor, a standing committee of subject matter experts and education specialists, NCES, and the Governing Board, which has final approval of all items. In addition, NAEP items in some subjects are reviewed by state and district representatives. All items are pilot tested with a nationally representative sample to evaluate performance before being selected for an operational NAEP assessment used for reporting.

NAEP is a survey of representative samples of students at the national, state, or district level and reports group estimates for populations of students at these levels. NAEP does not provide individual student or school scores, and no single student takes the entire assessment in a given subject (as described in the Assessment Design section of this entry below). Schools are selected from a sampling frame and then students are randomly selected from the appropriate grade at each sampled school. For national-only samples, typically about 8,000–12,000 students are assessed per subject, per grade in roughly 400–650 public and private schools. For state samples, each state has roughly 2,500–3,000 students per subject per grade in about 100 public schools, resulting in more than 150,000 students in the combined national and state sample. Each district sample has about 1,000–2,000 students per subject per grade in roughly 20–100 schools.

Findings based on NAEP data are released to the public through the Nation's Report Card. NAEP reports use two primary methods of reporting student achievement for both current year and trend performance: average scale scores and percentage of students at each NAEP Achievement Level. The NAEP Achievement Levels are Basic (partial mastery), Proficient (solid academic performance), and Advanced (superior performance). For each subject and grade, preliminary Achievement Levels are defined in the framework. After the first operational assessment, the minimum scores corresponding to each Achievement Level are set by the Governing Board. Performance data and questions from the assessment are also used to develop detailed descriptions and examples of the specific knowledge and skills at each Achievement Level.

Results are reported at the national, state, and district level, for different percentiles (10th, 25th, 50th, 75th, and 90th) to show performance at the lower, middle, and higher levels and by key subgroups such as gender, race/ethnicity, SD/ELL status, and eligibility for the National School Lunch Program (as an indicator of SES). Reports may also include results for other demographics and key background variables in the student, teacher, or school questionnaires. All together, the NAEP reports help inform education policy makers and the public.

History of NAEP Science

The first NAEP science assessment was in 1969. From its inception, NAEP was administered to students aged 9, 13, and 17. In the 1980s, NAEP also started including grade-based samples in the grades containing the largest proportion of students in the age-based populations. The current main NAEP assessments at grades 4, 8, and 12 began with the establishment of the Governing Board in 1988 and the transition to national and state-level reporting. The national age-based assessments continued as long-term trend. Both LTT and main NAEP national science assessments were administered and reported separately in the 1990s; the last LTT assessment in science was in 1999.

In addition to the national assessments, in 1990 main NAEP started conducting state-level assessments. The first state-level science report was in 1996. State-level science assessments were administered at grades 4 and 8 in 2000, 2005, and 2009 and at grade 8 in 1996 and 2011. Starting in 2002, NAEP has also conducted a Trial Urban District Assessment (TUDA) in select large urban districts. In science, ten districts participated in 2005 and 17 districts in 2009.

Table 1 below shows the main NAEP science assessments conducted (or planned) at the national, state, and district (TUDA) level, as well as the LTT assessments, from 1969 to 2015.

National Assessment of Educational Progress (NAEP), Table 1 NAEP science assessments 1969–2015

	Main NAEP			Long-Term Trend
Year	National	State	TUDA	(LTT)
1969–70			✓	✓
1973				✓
1977				✓
1982				✓
1986	†			✓
1990	✓			✓
1992				✓
1994				✓
1996[a]	✓	✓ (8)		✓
1999				✓
2000	✓	✓ (8)		
2005	✓	✓ (4 & 8)	✓ (4 & 8)	
2009[b]	✓	✓ (4 & 8)	✓ (4 & 8)	
2011[c]	✓ (8)	✓ (8)		
2015	✓	✓ (4 & 8)	✓ (4 & 8)	

✓Check marks indicate an assessment was administered or planned and reported this year at all three grades (4, 8, and 12) for main NAEP or at all ages (9, 13, and 17) for long-term trend (unless otherwise noted). National, state, and Trial Urban District (TUDA) assessments are indicated for main NAEP

†This symbol denotes a special case. There was one science report from 1986, which included both trend results for LTT age-based samples and achievement results for grade-based samples. This was the first combined age/grade sample for science administered at the modal grades (grades 3, 7, and 11) for the LTT populations (ages 9, 13, and 17). LTT populations were redefined starting in 1988 to have modal grades of 4, 8, and 12

[a] This was the first assessment based on a new science framework, developed by the Governing Board, which established the trend line from 1996 to 2005

[b] A new framework was developed for the 2009 assessment, establishing a new trend line

[c] The 2011 science assessment was conducted at grade 8 only to facilitate a comparison between NAEP and the Trends in International Mathematics and Science Study (TIMSS)

Long-term trend reported trends in science achievement from 1969 to 1999. For main NAEP, there were three assessments in the trend line based on the first Governing Board science framework: 1996, 2000, and 2005. A new trend line was established in 2009 with the introduction of a new science framework.

The most recent science framework was used as the basis for the assessments conducted in 2009 and 2011, as well as the development of upcoming assessments. The 2009 framework reflected developments in national science standards and state and international assessments, as well as advances in science and cognitive research since the early 1990s. The 2009 framework is sufficiently different from the previous framework that a new trend line was started.

The 2009 NAEP Science Framework

There are two dimensions in the 2009 science framework that define the science knowledge, skills, and abilities to be measured in the science assessment: science content and science practices. A separate assessment and item specifications document provides more detailed information on the content to be assessed, item types, and other aspects of assessment development and administration.

The science content dimension defines the key science principles as well as facts, concepts, laws, and theories to be assessed. The content dimension is organized into three broad content areas:

- Physical science
- Life science
- Earth and space sciences

Each of the content areas includes a set of major topics and subtopics that further organize the science content to be assessed. The content to be assessed at each grade level is defined by a set of grade-specific content statements for each subtopic. Each subtopic also has an associated set of content boundaries in the assessment specifications document that further clarifies the content included and excluded at each grade. The framework also emphasizes the importance of cross-cutting content (such as energy transformations and biogeochemical cycles), which includes key science principles reflected in the content statements across the content areas.

Table 2 shows the subtopics included in each content area and the target percentage of the assessment across the content areas at each grade level defined in the framework.

National Assessment of Educational Progress (NAEP), Table 2 Distribution of assessment time by grade and subtopics included in the content areas in the NAEP 2009 science framework

Content area	Grade 4	Grade 8	Grade 12	Subtopics
Physical science	33.3 %	30.0 %	37.5 %	Properties of matter
				Changes in matter
				Forms of energy
				Energy transfer and conservation
				Motion at the macroscopic level
				Forces affecting motion
Life science	33.3 %	30.0 %	37.5 %	Organization and development
				Matter and energy transformations
				Interdependence
				Heredity and reproduction
				Evolution and diversity
Earth and space sciences	33.3 %	40.0 %	25.0 %	Objects in the universe
				History of Earth
				Properties of Earth materials
				Tectonics
				Energy in Earth systems
				Climate and weather
				Biogeochemical cycles

The second dimension of the framework is defined by four science practices that describe what students should be able to do with the science content:

- Identifying science principles focuses on students' ability to recognize, recall, define, relate, represent, and reason with basic science principles.
- Using science principles focuses on what makes science knowledge useful in making

National Assessment of Educational Progress (NAEP), Table 3 Distribution of assessment time by grade and general performance expectations included in science practices in the NAEP 2009 science framework

Science practice	Grade 4	Grade 8	Grade 12	General performance expectations
Identifying science principles	30 %	25 %	20 %	Describe, measure, or classify observations
				State or recognize correct science principles
				Demonstrate relationships among closely related science principles
				Demonstrate relationships among different representations of principles
Using science principles	30 %	35 %	40 %	Explain observations of phenomena
				Predict observations of phenomena
				Suggest examples of observations that illustrate a science principle
				Propose, analyze, and/or evaluate alternative explanations or predictions
Using scientific inquiry	30 %	30 %	30 %	Design or critique aspects of scientific investigations
				Conduct scientific investigations using appropriate tools and techniques
				Identify patterns in data and/or relate patterns in data to theoretical models
				Use empirical evidence to validate or criticize conclusions about explanations and predictions
Using technological design	10 %	10 %	10 %	Propose or critique solutions to problems given criteria and scientific constraints
				Identify scientific trade-offs in design and decisions and choose among alternative solutions
				Apply science principles or data to anticipate effects of technological design decisions

sense of the natural world, with an emphasis on explaining and predicting.

- Using scientific inquiry involves applying science principles to answer a question under investigation to extend knowledge and to evaluate evidence, focusing on a few key inquiry practices that are practical to measure.
- Using technological design involves applying science principles to make design decisions.

Table 3 shows the general performance expectations for the four science practices and the target percentage of the assessment at each grade level defined in the framework.

The practices are combined with the content statements to generate specific student performance expectations which are used to develop assessment items.

The framework also describes four cognitive demands that underpin the science practices: declarative knowledge (knowing that), schematic knowledge (knowing why), procedural knowledge (knowing how), and strategic knowledge (knowing when and where to apply knowledge). The cognitive demands provide further elaboration on the skills to be measured by items across the science practices.

There are three components of the science assessment described in the 2009 framework:

- Individual assessments items (administered in paper-and-pencil test booklets)
- Hands-on performance tasks (HOTs)
- Interactive computer tasks (ICTs)

A range of item types is reflected in the framework, including individual items, item clusters that provide a more in-depth measure of particular science concepts, and item sets that require students to predict, observe, and/or explain phenomena. The assessment includes both selected-response (multiple-choice) items and constructed-response items where students are required to generate a written response to the questions. Both short constructed-response items requiring a brief description or quantitative relationship and extended items requiring more complete explanations are included. Constructed-response items have item-specific scoring guides with criteria for complete, partial, and incorrect score levels. Short constructed-response items may have two or three score levels, while extended items may have four or five levels. The framework requires that constructed-response items contribute 50 % of the assessment time.

Both HOTs and ICTs involve investigations and problem-solving scenarios that require students to directly apply their science knowledge and inquiry and problem-solving skills to real-world situations. Hands-on tasks require students to work with physical materials and science tools and have been included in NAEP science since the 1996 assessment. However, the 2009 framework calls for more open-process tasks that allow students to determine procedures and involve more planning, analysis, and synthesis. When performing HOTs, students collect and record data and provide responses to items in a test booklet. Most items in HOTs are constructed response, which are scored to assess both science content knowledge and inquiry skills.

The 2009 science framework was the first NAEP assessment to include interactive computer tasks. The framework defines four basic types of ICTs:

- Information search and analysis
- Empirical investigation
- Simulation of phenomena and models
- Concept mapping

Each task includes elements of one or more of these basic types. The ICTs provide opportunities to use phenomena not easily observed, involve lab situations that would be unsafe or impractical in the HOTs, include simulated internet search environments, and more easily measure the iterative nature of the inquiry and design process. When taking the ICTs, students respond to individual items (selected and constructed response). In addition, student actions as they proceed through the task are also captured and scored.

Assessment Design

The results reported in the Nation's Report Cards from the 2009 and 2011 assessments were based on student performance on the main paper-and-pencil assessment items. NAEP science assessments typically include between 150 and 200 individual items at each grade that cover the content areas and practices in the assessment framework. Assessment items from each content area are assembled into 25-min blocks; these blocks are paired in multiple test booklets that are distributed across the student sample. Each student takes two blocks – about 30–35 total items depending on the number of multiple-choice and constructed-response items in each block – which reflects only a fraction of the total assessment. This design ensures broad content coverage across the large item pool while minimizing the test burden on individual students. Since individual student scores are not reported, NAEP uses scaling methods that produce group estimates for populations at the national, state, or district level based on the subset of item responses obtained from each student in the sample.

The 2009 assessment also included two 40-min hands-on performance tasks and three interactive computer tasks (two 20-min and one 40-min) at each grade. These new components of the assessment were administered as a "probe" to separate, nationally representative samples in 2009 and were not combined with the results from the main paper-and-pencil assessment. The results from the 2009 HOT and ICT probes were reported separately from the main results.

The 2011 assessment was conducted at grade 8 only and was added to the assessment schedule for a special study linking NAEP to the Trends in International Mathematics and Science Study (TIMSS). The 2011 assessment included only the main paper-and-pencil component; the HOTs and ICTs were not administered in 2011. For more information about the NAEP-TIMSS linking study, see http://nces.ed.gov/timss/naeplink.asp.

Reporting and Release

Results from the 2009 assessment were reported at the national level at grades 4, 8, and 12. Results were also reported for grades 4 and 8 at the state level and for the 17 large urban districts that participated in the assessment. In 2011, the assessment was administered at grade 8, and results were reported at the national and state level. The 2011 assessment at grade 8 provided the first trend measure based on the new science framework. Science reports from 2009 and 2011 as well as some previous assessments may be accessed on the Nation's Report Card website (http://nces.ed.gov/pubsearch/getpubcats.asp?sid=031).

The results from the 2009 HOT and ICT probes were published in a separate 2012 report (Science in Action-Hands-On and Interactive Computer Tasks from the 2009 Science Assessment) that provides more in-depth information about students' abilities to conduct investigations, draw conclusions, and explain their results.

NAEP reports average science scores on an overall scale (0–300) based on all items in the assessment at each grade. In addition, subscales are produced for each of the content areas – physical science, life science, and Earth and space sciences. While performance on the subscales is not a focus in the main reports, subscale scores are available on the NCES website.

The 2009 assessment was the first assessment based on the new framework. Using student performance data and items from this first assessment, the Governing Board established the Basic, Proficient, and Advanced Achievement Levels for the science assessment. Descriptions of the science knowledge in each content area as well as the skills in the science practices that characterize each Achievement Level at each grade are provided in the updated 2011 framework (see References below).

The NAEP reports also include item maps and example items to illustrate student performance across grades and content areas. Item maps are visual representations that show the location of the Achievement Levels and place a range of items on the scale based on their difficulty. This provides a method for describing the types of items students at a given score level were likely to be able to do (http://nces.ed.gov/nationsreportcard/itemmaps/?subj=science).

After each assessment, a subset of items is released to give the general public a better understanding of the content of the assessment. New items are developed to replace these released items for the next assessment. The released items, along with performance data and scoring guides, are provided in the NAEP Questions Tool at http://nces.ed.gov/nationsreportcard/itmrlsx/landing.aspx. For science, released items are available from the 2009 and 2011 assessments as well as previous assessments based on the prior framework (2005 and 2000).

All of the ICTs and one of the HOTs at each grade were released after the 2009 assessment. Teachers, students, parents, researchers, and the general public are able to explore the tasks and take the ICTs themselves online (http://nationsreportcard.gov/science_2009/ict_summary.asp). Users can also access the full text of the released HOTs as well as descriptions of the materials and tools used in the tasks at http://nationsreportcard.gov/science_2009/ict_tasks.asp?tab_id=tab2%26subtab_id=Tab_1#tabsContainer.

The NAEP Data Explorer (NDE) permits users to define demographics or contextual variables of interest from the NAEP data and create their own customized tables of results for the nation, state, district, or for different subgroups using either the overall science scale or the content area subscales (http://nces.ed.gov/nationsreportcard/naepdata). Restricted-use data sets are also available to licensed researchers to conduct secondary analyses using NAEP data (http://nces.ed.gov/nationsreportcard/researchcenter/researchsupport.asp).

Future of NAEP

The next NAEP science assessment is currently planned for 2015 and will include the main assessment item blocks, hands-on tasks, and interactive computer tasks in the national assessment. With the release of all of the 2009 ICTs and half of the HOTs, the 2015 assessment will reflect the next generation of tasks currently under development. Following the standard cycle of science assessments every 4 years, the subsequent science assessment is scheduled to be conducted in 2019.

NAEP's move to computer-based assessment started with the ICTs in the 2009 science framework followed by the 2011 writing framework and the 2014 technology and engineering literacy framework. The Governing Board plans to transition each assessment to computer-based administration with each new framework. Although there are no current plans to replace the 2009 science framework, it is anticipated that the science assessment will transition to being fully computer based over the next two administrations.

NCES is exploring a number of other options to move the NAEP program forward. In 2011 and 2012, NCES convened panels of experts in assessment, measurement, and technology as well as state and local stakeholders to provide recommendations on the future of NAEP (10 years ahead and beyond). The paper with recommendations from the panel (NAEP: Looking Ahead – Leading Assessment into the Future) is available on the NAEP website (http://nces.ed.gov/nationsreportcard/pdf/Future_of_NAEP_Panel_White_Paper.pdf).

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National Assessment Governing Board Website: http://www.nagb.org/

Nations Report Card Website: http://nces.ed.gov/nationsreportcard/

Nature of Science

▶ Nature of Science, Assessing of
▶ NOS: Cultural Perspectives
▶ NOS, Measurement of

Nature of Science, Assessing of

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Conceptualizing the Construct of NOS

Although the current terminology for this construct is "nature of science," it was originally labeled "nature of scientific knowledge" until the mid-1980s. The latter phrase typically refers to characteristics of scientific knowledge as derived from the manner in which it is produced, that is, scientific inquiry (Lederman 2007, McComas 1998). In short, the method of developing scientific knowledge necessarily imbues the knowledge with certain characteristics. When discussing assessment, it must be recognized that NOS has consistently been viewed in the literature as a cognitive outcome. That said, in recent years, some science educators have included some aspects of inquiry (the doing of science) as part of NOS. Traditionally, however, NOS has not been viewed as a skill, attitude, or activity. Additionally, there is a developmentally appropriate level of generality regarding NOS that is accessible to K-12 students and relevant to their daily lives. At this developmental level, little disagreement exists among philosophers, historians, and science educators. It is important to note that the description of NOS that follows is not meant to be a definitive depiction, but rather represents the most common aspects of NOS used in the research literature and taught to K-12 learners.

First, students should be aware of the distinction between observation and inference. In K-12 science classrooms, observations are presented as descriptive statements about natural phenomena that are "directly" accessible to the senses (or extensions of the senses). By contrast, inferences are presented as statements about phenomena that are not "directly" accessible to the senses. The notion of gravity is inferential in the sense that it can only be accessed and/or measured through its manifestations or effects. It is also critically important that students know that both observation and inference are necessarily part of all scientific knowledge.

Second is the distinction between scientific laws and theories. Individuals often hold a simplistic, hierarchical view of the relationship between theories and laws whereby theories become laws when overwhelming supporting evidence is accumulated. For example, biology teachers are often told that evolution is just a theory. This notion is inappropriate. Laws are statements or descriptions of the relationships among observable phenomena. Theories, by contrast, are inferred explanations for observable phenomena. Scientific theories serve important roles, such as guiding investigations and generating new research problems in addition to explaining relatively huge sets of seemingly unrelated observations in several fields of investigation. Although scientific theories and laws are related, it is incorrect to think that theories eventually mature into laws.

Third, even though scientific knowledge is, at least partially, based on and/or derived from observations of the natural world (i.e., empirical), it nevertheless involves human imagination and creativity. Because science is done by humans, it is not a totally lifeless, rational, and orderly activity. Science involves the human invention of explanations and the generation of ideas. This requires a great deal of creativity by scientists. This aspect of science, coupled with its inferential nature, entails that scientific concepts are functional theoretical models rather than faithful copies of reality.

Fourth, scientific knowledge is subjective and theory laden. Scientists' beliefs, previous knowledge, training, experiences, and expectations, in addition to theoretical commitments, influence their work. These background factors form a mind-set that affects what problems scientists investigate, how they conduct their investigations, what they observe, and how they make sense of, or interpret, observations. It is this (sometimes collective) individuality or mind-set that accounts for the role of subjectivity in the production of scientific knowledge; while not intended, it is, nonetheless, unavoidable.

Fifth, science as a human enterprise is practiced in the context of a larger culture and its practitioners (scientists) are the product of that culture. Scientific knowledge affects and is affected by the various elements and intellectual spheres of the culture in which it is embedded. These elements include, but are not limited to, social fabric, power structures, politics, socioeconomic factors, philosophy, and religion.

Sixth, it follows from the previous discussions that scientific knowledge is never absolute or certain. This knowledge, including "facts," theories, and laws, is inherently tentative or subject to change. Scientific claims change as new evidence, made possible through advances in technology, is brought to bear on existing theories or laws, or as old evidence is reinterpreted in the light of new theoretical advances or shifts in the directions of established research programs. Although scientific knowledge is “tentative,” it is also quite durable as knowledge is not accepted without a wealth of supporting evidence.

NOS Assessment Methods and Interpretations

Assessing NOS knowledge has been approached through a variety of instruments (see “▶ NOS, Measurement of”) (Driver et al. 1996). Early instruments were multiple choice and Likert scale measures, such as the Test on Understanding Science (TOUS) from Klopfer and Cooley and Nature of Scientific Knowledge Scale (NSKS) from Rubba (see Lederman 2007, McComas 1998, for a comprehensive listing). These forced-choice instruments were widely used and provided numerical scores that were equated with a level of overall proficiency in respondents’ NOS understanding. The results consistently showed respondents held inadequate conceptions of NOS. The problem, however, is that a single score does not provide sufficient information as to learners’ actual conceptions of various NOS aspects. Based on this score, learners were placed into categories predetermined by the instrument developers (e.g., traditional, nontraditional). In order to inform curriculum development and instruction, more detailed descriptions of conceptual understanding are necessary.

It was not until open-ended survey instruments and interview approaches were introduced that specific misconceptions and areas of difficulty were elucidated. Questionnaires such as the Views of Nature of Science (VNOS) (Lederman et al. 2002) and interview protocols provide opportunities for respondents to articulate their ideas using their own words, examples, context, and rationale. NOS assessments based on open-ended survey and interview measures provide descriptive profiles that include multiple NOS aspects, contexts, and finer nuances of conceptual understanding than is possible with a numerical score from forced-choice items. Interpreting written and verbal responses is based on targeted NOS aspects such as those described above. Interpreting responses leads to a profile of how the respondent describes each aspect and connections among aspects. Profiles can then be compared to desired or accepted descriptions. Profiles include descriptors such as “informed” and “naïve” to indicate the degree to which a learner demonstrates an acceptable or unacceptable view of each targeted aspect. For example, an “informed” view of the tentative NOS would entail consistent reporting that scientific knowledge is inherently subject to revision or change. Such change can result from new information or reinterpretation of existing information. An informed learner would also be able to provide examples and rationale for when and why scientific knowledge would change. A “naïve” view is demonstrated by stating that scientific knowledge represents truth and therefore does not change once developed and accepted. A “naïve” view would describe scientific laws as proven, absolute truths. Assessments have suggested learners can hold transitional or emergent positions with respect to how they understand certain NOS aspects. Evidence for a transitional view is one which the responses are inconsistent, perhaps by context or by aspect. For example, the learner may express understanding that scientific knowledge is inherently subject to change, but still hold the notion that scientific laws, being unchangeable, are the exception.

Representing NOS views on a continuum (naïve – emergent – informed) is useful for tracking changes in views of targeted NOS aspects. NOS assessments and associated interpretation provide researchers and teachers insights into learners’ cognitive understandings of NOS concepts and characteristics. NOS assessments that target conceptual knowledge (e.g., VNOS) have been successful in identifying challenges and misconceptions learners hold and identifying instructional approaches that are effective in addressing these issues.

Despite these successes, there are other assessment approaches that assume a different description of NOS as a construct. Some researchers assume that learners' NOS understandings are assessable through observation of actions during scientific inquiries. This view describes NOS as an epistemic construct demonstrable through behaviors. How someone "does science" is assumed to represent their abilities and NOS understandings. Observing science in practice can provide insights into scientific skills and even reasoning, both important learning outcomes, but not NOS learning outcomes. Research clearly demonstrates inconsistencies between NOS views and teaching approaches as well as scientific abilities. NOS beliefs are not necessarily displayed through behaviors or attitudes. Relying on behavioral measures such as observing students in a laboratory is not enough and, in fact, is insufficient for assessing NOS knowledge.

Assessing NOS Within Instruction

Because NOS-related learning outcomes are cognitive in nature, asking students to articulate their knowledge and understandings about NOS can serve to assess student attainment of these learning outcomes. Equally important, evidence pertaining to the assessment of NOS-related learning outcomes could be generated from asking students to reflect on their actions as they engage with science learning experiences. Students' reflections make the latter approach clearly distinct from attempting to infer student NOS understandings from observing those actions.

Realizing that NOS is a cognitive learning domain serves to demystify the measurement of student learning about NOS. This realization makes available to science teachers a variety of formative and summative assessments that could be used to gauge student progress toward achieving, and achievement of, NOS-related learning outcomes, respectively. Additionally, this perspective allows drawing on a host of science learning experiences as contexts to measure student NOS understandings. These experiences include, among other things, exploring scientific theories and concepts, inquiry-based investigations, discussions of socio-scientific issues, and engagement with science-related texts and narratives. The latter materials include historical case studies, popular science writings and media productions (e.g., popular science books, science-related news reports and press releases, documentaries), and scientific publications. Regardless of the context, instruction and assessment must be purposeful and explicit.

For example, in the context of learning about the geosphere, seventh grade students could be asked, "We seem to know a lot about the structure of the geosphere. How is this knowledge possible given that our deepest explorations have barely scratched the surface of the Earth's crust?" This and similar questions provide opportunities for students to articulate their understanding of the distinction between pertinent observations, such as seismic waves, and an inferred claim or explanation, that is, the model of the geosphere. Similar discussions can be situated in various science topics and serve to gauge whether students have internalized the understanding that observations do not speak for themselves, but always require interpretation on the part of scientists.

Historical case studies provide ample opportunities to measure NOS understandings (see "► History of Science, Assessing Knowledge of"). For instance, after examining a narrative on John Snow and the Broad Street pump, tenth grade students could be asked, "How did Snow identify the source of contamination by observing the scatter dot maps of deaths associated with the 1854 Cholera outbreak in central London?" Student responses could help gauge their understanding of the role of theory in guiding data collection and interpretation. Indeed, Snow's contagion theory served him well in collecting pertinent data, interpreting other evidence, and pinpointing the contamination source. In contrast, the prevailing miasma theory of the time had failed others who attempted to solve the mystery.

Socio-scientific issues and explicit instruction can help students understand the interface between science and society and the resultant issues, such as whether scientists should be permitted to patent genetically engineered organisms. Teachers ask students to articulate the positions, beliefs, and values (economic, aesthetic, cultural, etc.) of the players involved with such issues. In this context, students could be asked, “To what extent did the beliefs and values you attributed to scientists play a role in their position? Defend your answer with evidence generated from examining the published articles about the debate.” Student reflections provide access to their conceptions of the cultural embeddedness of science.

Inquiry activities provide an exemplary context to gauge student understandings of aspects, such as the inferential and theory-laden NO-S. Teachers can ask students to identify observations and inferences in their reports and justify the distinction, or link certain aspects of their investigations to their understanding of the role of theory or prior ideas in choosing what data to collect.

Cross-References

- ▶ Assessment of Doing Science
- ▶ Epistemology
- ▶ Epistemic Goals
- ▶ NOS: Cultural Perspectives
- ▶ NOS, Measurement of

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Neuroscience and Learning

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Cognitive functions; Cognitive neuroscience; Learning methods; Learning process

Introduction

Education in the twenty-first century is characterized by a number of features that contrast greatly with education of, say, 50 years ago. First, learning is not understood in the way it was earlier. Today considerations of learning are not restricted to a selected type of methodologies but employ a plethora of methods, strategies, and approaches. Secondly, learning contexts today often encompass a diversified group of people, of different age, gender, social and professional backgrounds, and participating in education – schooling or training – for a very wide range of reasons. And a dramatically growing field of education is online learning, offering courses to endlessly diversified audiences located in very distant countries. The field of learning science is nowadays characterized by diversity in terms of learners, learning environments, and learning methods. As a consequence of these multiple diversities, there is a growing demand for interdisciplinary and advanced research on education in order to foster the processes of acquiring knowledge in different settings and for different audiences, as well as to enhance the potential of educational institutions in a world that has no effective geographic boundaries.

In recent years there has been a dramatic advancement in interest in neuroscientific research and in its methods of investigation. This advancement is facilitating our evolving understanding of how to stimulate learning processes and increase one's learning potential, including being better able to take into account individual needs of learners. In general, research on neuroscience in learning encompasses the processes and participants taking part in education, understood in the broadest sense. Thus, the focus in this research is on the various stakeholders taking part in learning and teaching, the place they hold in the educational context, and the activities related to providing and receiving education (all analyzed from the neuroscientific perspective). The growing role of neuroscience in various fields of life has influenced the sphere of education, giving rise to such subdisciplines as neuroeducation or educational neuroscience. There are also such terms as neuropedagogy, neurodidactics, neuroteaching, and neurolearning used to denote the neuroscientific character of educational subbranches.

Neuroscience and learning can also be examined by taking into account a particular domain of study. Thus, such areas as neurolinguistics, neuromanagement, neuroeconomics, etc., can be distinguished, narrowing the scope of investigation to the learning processes taking place in a given domain. In addition, researchers dealing in cognitive neuroscience, cultural neuroscience, social neuroscience, and neuropsychology also address the issue of learning in their studies. Concentrating on the linguistic aspects in learning, neurolinguists study how language is learned and used, by paying attention to the processes taking place in the brain that are caused by education and simultaneously determine learning. On the other hand, neurobiologists are interested in the biological aspect of the nervous system and the biological aspect of learning processes. Taking into account the sphere of neuromanagement, neuroscientists may be interested how managers acquire new organizational knowledge and how the processes of learning influence their corporate performance. In addition, those specializing in neuromarketing pay attention to how customers learn about new products and services as well as how the knowledge they acquire to determine their selection of offered merchandise. In addition, neuroethics and neurostrategy offer additional information on learning in corporate settings, by taking into account corporate social responsibility and organizational goals, respectively (Bielenia-Grajewska 2013).

As yet there has been relatively little neuroscientific research in the specific domain of learning science. Consequently, there is more conjecture about possibilities than analyses of extant research in the remainder of this entry. However, all the above emerging neuroscience specialities have potential to also contribute to our understanding of the learning of science. Neuroscientific investigations of learning science can also be researched through the perspective of tools employed to educate stakeholders in the field of science as well as through the prism of those taking part in learning processes.

Participants in Learning

There are various approaches that can be used in the discussion of neuroscience and learning science, for example, by concentrating on participants/entities or on processes in education. Below I focus on entities, from which perspective the research may focus on learners, on teachers, or on the broadly understood context for the learning or tasks involved in the learning.

Learners and Neuroscience

The concept of a science learner can be viewed in two ways. One is a fixed approach, concentrating on the well-established dichotomy between learner and teacher, often set up in a classroom environment. The second perspective is a dynamic one, stressing the flexibility of roles in learning science. Thus, a teacher will also be a learner in situations aimed at enhancing his or her knowledge (e.g., self-study, professional courses, postgraduate education). No matter which approach is taken, the aspects of learner and neuroscience encompass individual characteristics. Thus, such factors as culture, age, and gender shape one's attitude to learning. For example, one's age may determine the willingness to opt for some learning methods (e.g., games for children or social networking tools for young learners). Another important aspect of learning is the purpose of schooling or training. Thus, one's reason for joining a course determines the selection of materials used in self-study or in formal classes to reach the learning objectives. For example, a scientist preparing his or her speech for a conference may be more willing to practice conversational skills than enhance his or her writing expertise. On the other hand, a researcher writing a scientific report or an article will likely favor developing writing proficiency over speaking skills to enhance the quality of his or her publications. The domain of learners can be enlarged by taking pupil's or student's parents or legal guardians. One of the aspects that can be investigated is the attitude of learners' families towards learning processes and their own preferences regarding schooling and learning science. In that case, those in the direct environment of a learner can be studied by showing how their behavior and own learning selections influence learners' performance.

Teachers and Neuroscience

A teacher is studied by taking into account individual features that determine one's teaching style. Thus, such notions as gender, age, or educational background can be studied in relation to how science teaching is undertaken. In addition, teachers can also be viewed as learners, taking into account their own education and additional training. Thus, teacher's learning abilities can also be investigated, e.g., by paying attention to how teachers comprehend new methods of education, new scientific data, or new tools in schooling. Such studies may include, e.g., the analysis of training devoted to the usage of social online networking tools in teaching or web auditoriums in modern education. As in the case of the abovementioned concept of a learner, teacher can be treated as both a fixed and dynamic notion. The fluid dimension may encompass learners being teachers in some situations since interactions between teachers and learners offer knowledge flows between both sides participating in science exchange. For example, learners' attitude to presented scientific materials or their learning potential offers teachers important feedback how to select new materials for teaching science in an effective way.

Contexts for Learning and Learning Tasks

Research concentrating on neuroscience approaches to understanding more of the processes of learning science may also focus on the characteristics of a given type of education. Learning science can be categorized into conscious and unconscious learning. In this case, learning is researched by taking the notion of active participation into account and distinguishing between implicit and explicit learning. Thus, researchers may investigate how individuals acquire scientific knowledge while concentrating exclusively on learning tasks or while performing other activities simultaneously. Another determinant of learning science is the number of learners taking part. Thus, individual and group instruction can be investigated. In the case of participants' influence on learning, one of the issues that can be studied is how the number of students determines individual cognition and participation in the group. Another option for research is checking the advantages or disadvantages of individual tutoring.

A different classification encompasses formal and informal learning. This distinction provides the opportunity to study the role of formality in learning and how informal and formal settings determine one's cognition and perception. Learning can also be explored by taking into account the place of learning – home, classroom, company, or the Internet. Learning can also be categorized by taking into account both standard and novel methods of learning, with the latter being subdivided into offline and online learning. Analysing the growing role of new technologies, such issues as electronic learning and mobile learning can be distinguished as well. Learning can focus on using one mode of gaining knowledge, or it can be more complex, engaging different activities simultaneously (e.g., walking for exercise and listening to tapes of material one is seeking to learn at the same time). In this case, neuroscience researchers are interested how the interrelation between psychomotor and cognitive functions works in practice. These issues are also important in teaching science in less complex forms for younger ages, e.g., in nurseries and kindergartens.

Issues in Neuroscience and Education

Memory

In the field of neuroscience, researchers are interested in various factors that determine the processes of acquiring and storing knowledge and using it when required. Both short-term and long-term memory are addressed. In addition, different channels of instruction are taken into account. Thus, researchers can study how memory functions when instruction is done through, for example, either auditory or visual channels. It may help teachers select materials for reading and listening comprehension as well as understand the role of speaking and talking in learning new scientific ideas. Another notion studied is the way different factors such as age, gender, or education may potentially determine the processes of encoding, decoding, and storing knowledge, engaging different types of memory. Such knowledge may facilitate the preparation of learning materials that suit the needs of the target audience and their cognitive abilities. Another role of studies on memory is to find out how people with memory problems can be more effectively taught. Neuroscience is interested, among other things, in observing how patients with memory loss or dementia can acquire and store scientific knowledge. Taking into account the notion of memory and durability of information, neuroscientists examine how long certain scientific concepts are stored in memory and what determines for how long they are stored.

Methods and Processes

Learning in the twenty-first century has different expectations, since today teaching and learning often take place in diversified environments. One such an example is teaching and learning foreign languages in a corporate setting. The group of those who want to study language for professional purposes often entails participants coming from different professional backgrounds, representing different age groups and with different levels of desired expertise (Bielenia-Grajewska 2011). Similarly, modern methodologies of learning must encompass diversified methods of investigating learning processes to meet the needs of those having different levels of knowledge in a given scientific domain and various expectations regarding the curriculum. Moreover, neuroscience can potentially provide an answer as to which strategies are better for teaching and learning science. It may enhance the creativity of teachers as far as selection of teaching method is concerned. Applying a processual perspective, neuroscientists study the factors and results connected with learning and teaching procedures as far as knowledge flows are concerned.

Another sphere of interest may be the language of instruction, via the study of the characteristics of bilingual and multilingual education. In this case, language can be investigated as a factor facilitating or diminishing scientific exchanges. In addition, since the multilingual sphere of learning encompasses the role of minority linguistic rights, researchers are also interested in how the attitude to linguistic rights determines learning processes and access to scientific knowledge.

Another approach to learning is through the channels of communication used in different forms of schooling and tutoring. This includes verbal and nonverbal strategies directed at making learning efficient, concentrating on the language as well as pictures used in encoding and decoding information. In addition, attention can be paid to online and offline methods in education. Within the verbal sphere of scientific exchange, neuroscience can facilitate the understanding of the role of figurative and nonfigurative tools of knowledge flows. For example, the use of metaphors in disseminating scientific data can be studied by observing how stakeholders perceive messages and how their reaction to risk is shaped by the symbolic language used in texts, in comparison with, say, more literal tools of communication. Another classification is the division of scientific knowledge into that which is specialized and that which is directed to laymen and how linguistic tools are selected to transfer scientific knowledge to different stakeholders.

Relations

Neuroscience helps to study the role of human relations in the processes of teaching and learning. Thus, teachers' roles in learning communities, distance in teacher-learner interactions, and group characteristics are studied, as well as their influence on the learning processes. Within this domain, the notion of classroom identity, in particular encompassing the relations connected with the sphere of education, can be used. This can also allow for studying education not only from the prism of teachers and learners but also by taking into account the role of both internal and external participants in education. As far as the internal sphere is concerned, administrative staff and the way school life is organized can be taken under scrutiny. The outer dimension may encompass legal, political and cultural factors and their influences on the shape of learning.

Learners with Special Needs

Another sphere of interest as far as learning and neuroscience are concerned is the issue of learning disorders, such as dyslexia, dysgraphia, dyscalculia, and dyspraxia, and the ways these learning difficulties influence the process of understanding and using scientific data. Neuroscience also facilitates understanding the learning processes of the deaf, the mute, the deaf-mute, and the blind; in the case of scientific knowledge, neuroscience may facilitate the research dedicated to finding the effective way of disseminating science to learners with special needs.

Teaching Environment

Learning may also be studied through the prism of teaching and learning environments. This issue may be understood in different ways, by taking into account the immediate and more distant surroundings. For example, the notion of space can be taken into account, studying how fixed and unfixed elements of classroom determine learning processes. Such investigations may involve the way a classroom is built, the distribution of furniture and colors, and the layout of chairs and tables. Learning can also be investigated by taking into account different regulations set up to organize classroom life. Studies may involve teaching times, division into single study units, number of hours per week, or number of students in a class. All these factors can be investigated by the use of neuroscientific tools to show how these determinants are important in learning processes. Another crucial notion in learning environment is how modern technology determines the shape of knowledge acquisition.

Environment can also be studied by taking into account a broader perspective, by looking at the role and the influence of politics, economics, and culture in learning processes. Another macro dimension that can be investigated through neuroscience is the legal sphere of learning; teaching environment can also be perceived through the perspective of norms and regulations determining the way learning is conducted. This dimension may include studying the role of age in starting education or the importance of division into stages in education (e.g., kindergarten, primary, and secondary school). Neuroscientists are interested how children who start schooling at the ages of 5, 6, or 7 cope with different activities. Another issue pertinent especially to the sphere of science is the issue of copyrights, trademarks, and patents.

Neuroscience can also be employed in that case to show the relation between the legal regulation of scientific achievement and their cognition by the wider audience. Learning from the neuroscientific perspective can also be studied by taking into account different levels of investigation. For example, neuroscientific research may concentrate on the micro level, determining how small elements in communication such as morphemes or words determine learning processes. This perspective may focus on both figurative and nonfigurative elements of a language, with metaphors being of particular relevance to science learning. Looking at the meso dimension of neuroeducation, research may focus on the role of texts selected for learning. Analyzing the macro approach, such concepts as learning methods and strategies may be the topic of neuroscientific investigation. It may include, e.g., the analysis of how brain works and how learners respond to questions in experiments conducted by the use of neuroscientific tools.

Tools Used in Educational Neuroscience

Different areas of the brain are responsible for different activities. For example, the hippocampus is studied as far as memory is concerned, whereas the frontal lobe is examined in research on attention or motivation. Since the nucleus accumbens is often taken into account in analyzing emotions, in the case of learning, it can be researched to show pleasure or fear related with schooling or training. The methodologies used in neuroscience can be divided into invasive and noninvasive tools. In the research devoted to learning, neuroscientists rely mainly on noninvasive tools that do not carry any risk for those participating in experiments. Such a technique is functional magnetic resonance imaging (fMRI). It is a neuroimaging technique that uses magnetic resonance to detect brain activities. Conducting fMRI is connected with realizing various stages of investigation involving the subject lying still in an MRI scanner for about 60–90 min. The initial stage lasting about 6–15 min is focused on anatomical/structural scans of the brain. The next stages are devoted to the participant taking active part in the experiment.

A subject may be asked to perform some activities, such as answering questions or selecting pictures. For example, a stimulus is made visible on a screen and a subject is asked to choose a response. When the tasks are performed by the subject, the MMRI records the BOLD signal (blood oxygen level depending) that indicates which areas of the brain are active and which are not. The results are later compared with the control scans performed in the first stage of an experiment (Kenning et al. 2007). Another technique involves studying facial expressions. Facial electromyography (EMG) facilitates the understanding of the face as the mirror of affection (e.g., fear, anger, and surprise), cognition (e.g., concentration and boredom), and personality (e.g., hostility, sociability, and shyness). It offers the measurement of nerve impulses to muscles that determine facial changes and expressions (Helander and Khalid 2012).

Electroencephalography (EEG) may also be used in observing the changes taking place when one studies science. This method is conducted by placing some electrodes on the subject's head in order to investigate differences in neural activities (Lee and Chamberlain 2007). The mentioned neuroscientific tools are used by researchers to investigate how science is perceived by specialists and laymen, how language may facilitate or hinder the processes of learning science, and how to foster the understanding of science among various stakeholders.

Summary

Learning science, due to its complexity in terms of stakeholders and issues involved, is studied in different disciplines. Among them it is neuroscience that offers a broad perspective of researching various participants in learning processes, observing both human and nonhuman elements in the way learning is conducted and perceived. The application of noninvasive tools facilitates the understanding of processes taking place in learning science, involving different types of learners, various learning spaces, and diversified methods of acquiring new knowledge.

Cross-References

- ► Classroom Learning Environments
- ► Code-Switching in the Teaching and Learning of Science
- ► Language and Learning Science
- ► Memory and Science Learning
- ► Representations in Science

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NOS, Measurement of

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Conceptualizing NOS

The phrase “nature of scientific knowledge” (NOS) typically refers to characteristics of scientific knowledge inherently derived from the manner in which it is produced, that is, scientific inquiry (Lederman 2007; McComas 1998). When discussing methods of measurement for NOS knowledge, the conceptualization of NOS must be clear. NOS has been described in various ways. With respect to what is relevant and appropriate for science teaching and learning, the literature strongly supports the view that NOS knowledge is a *cognitive* outcome rather than a skill, attitude, or activity. However, some descriptions include NOS among the realm of scientific epistemic activities represented by skills and reasoning practices. Both of these views describe important learning outcomes but present, and thus measure, NOS in different ways.

NOS as a Cognitive Outcome Versus Epistemic Activity

Despite the debates, there is a developmentally appropriate level of generality regarding NOS that is accessible to K-12 students and relevant to their daily lives. At this developmental level, little disagreement exists among philosophers, historians, and science educators. These general, crosscutting characteristics representing the nature of scientific knowledge as a cognitive outcome are described in the table below. These aspects are not meant to be a definitive listing of NOS, but rather a representation of the most commonly measured aspects in empirical research dating back to the 1960s. Furthermore, these aspects are not to be considered in isolation from each other or from the scientific enterprise. Understanding of NOS includes understanding how these aspects are intricately connected and derived from the scientific enterprise.

NOS aspect	Description
Distinction between observation and inference	Students should be aware of the distinction between observation and inference. In the K-12 science classroom, observations are descriptive statements about natural phenomena that are “directly” accessible to the senses (or extensions of the senses) and about which several observers can reach consensus with relative ease. By contrast, inferences are statements about phenomena that are not “directly” accessible to the senses. The notion of gravity is inferential in the sense that it can only be accessed and/or measured through its manifestations or effects
Distinction between theories and laws	Closely related to the distinction between observation and inference is the distinction between scientific laws and theories. Individuals often hold a simplistic, hierarchical view of the relationship between

(*continued*)

NOS aspect	Description
	theories and laws whereby theories become laws depending on the availability of supporting evidence. This notion is inappropriate. Laws are statements or descriptions of the relationships among observable phenomena. Theories, by contrast, are inferred explanations for observable phenomena. Theories are as legitimate an evidence-based product of science as laws
Empirical basis	Even though scientific knowledge is, at least partially, based on and/or derived from observations of the natural world (i.e., empirical), it nevertheless involves human imagination and creativity. Science, contrary to common belief, is not a totally lifeless, rational, and orderly activity. Science involves the invention of explanations and the generation of ideas. This aspect of science, coupled with its inferential nature, entails that scientific concepts are functional theoretical models rather than faithful copies of reality
Subjective/theory driven	Scientific knowledge is subjective and theory driven. Scientists' beliefs, previous knowledge, training, experiences, and expectations, in addition to theoretical commitments, actually influence their work. These background factors form a mind-set that affects what problems scientists investigate, how they conduct their investigations, what they observe (and do not observe), and how they make sense of or interpret observations. It is this (sometimes collective) individuality or mind-set that accounts for the role of subjectivity in the production of scientific knowledge; while not intended, it is, nonetheless, unavoidable
Socially and culturally embedded	Science as a human enterprise is practiced in the context of a larger culture, and its practitioners (scientists) are the product of that culture. Scientific knowledge affects and is affected by the various elements and intellectual spheres of the culture in which it is embedded. These elements include, but are not limited to, social fabric, power structures, politics, socioeconomic factors, philosophy, and religion
Inherently tentative	It follows from the previous discussions that scientific knowledge is never absolute or certain. This knowledge, including "facts," theories, and laws, is inherently tentative and subject to change. Scientific claims change as new evidence, made possible through advances in theory and technology, is brought to bear on existing theories or laws or as old evidence is reinterpreted in the light of new theoretical advances or shifts in the directions of established research programs

This conceptualization of NOS distinguishes NOS knowledge from scientific practices or inquiry. Some researchers and theorists conflate NOS with science practices. This alternative view describes NOS as epistemic activity and emphasizes elements of scientific practices (Carey and Smith 1993; Sandoval 2005). Scientific practices represent what scientists do (such as asking questions, collecting and analyzing data, generating evidence-based claims through argumentation practices, etc.). Within this view, the practices of reasoning about evidence and critical evaluation of ideas are considered a part of NOS, as are recognizing multiple scientific methods and the use of scientific models and modeling. This view of NOS groups the knowledge and practices together and considers one's views of NOS to be represented through the actions of doing science. While intuitively appealing, this position is not well supported by the research that examines NOS knowledge (as described in the cognitive view) in relation to how one does science. A learner may be able to perform a controlled experiment and produce valid evidence-based claims; however, this same learner may not understand the role of creativity and inference that were involved in that process. Students can design experiments with valid controls, but not understand the necessity of having a control. Nonetheless, various views of what constitutes NOS still exist. Thus, when discussing NOS measurements, the conceptualization of NOS must be clarified.

Measurement of NOS knowledge is approached with the intention of determining learners' understanding of the concept and characteristics. The view that NOS is knowledge (the cognitive position) has been more consistently successful in directing measurement methods for the science learner and teacher. Research has demonstrated that actions and attitudes are not necessarily related to one's conceptual understanding of NOS. While observations can lead to inferences about one's investigative skills and reasoning abilities, relying on behavioral measures such as observing a scientist or a student in a laboratory is not enough and, in fact, is insufficient to infer NOS as knowledge. There is a need for cognitive measures.

Methods of Measurement

Historically, methods of measurement have ranged from Likert scale and forced-choice instruments to open-response surveys and interviews. In the 1950s, early efforts in instrument development included NOS among attitudes about science and scientists. Klopfer and Cooley then developed the *Test on Understanding Science* (TOUS) in 1961. The TOUS is a 60-item multiple choice test targeting understanding of the scientific enterprise, what a scientist is, and the method and purpose of science. The TOUS was widely used yet widely criticized for presenting a narrow depiction of NOS and scientists. These are common criticisms of forced-choice NOS instruments, including the *Nature of Scientific Knowledge Scale* (Rubba), *Nature of Science Scale* (Kimball), *Science Process Inventory* (Welch), among others (see Lederman 2007; McComas 1998, for a comprehensive listing). These earlier measurement approaches were primarily quantitative and quick to administer, thus quick to "grade." Total scores were reported. However, without explanation of what the score meant in relation to respondents' views of NOS, the results were limited. Forced-choice and Likert scale NOS measurements have been highly criticized for lack of validity, biased construction, and limited usefulness to inform researchers and teachers of how learners actually understand NOS and how NOS relates to other scientific knowledge.

In response, measurement efforts shifted to more qualitative and mixed-method approaches that enabled emergent descriptions of learners' NOS understandings. Open-ended surveys and interviews are accepted as more valid because this approach utilizes respondents' words, as opposed to the researchers' words and forced choices. Lederman et al. (2002); Driver et al. (1996); and others have demonstrated the importance of the survey/interview approach to gaining understanding of how learners describe characteristics of NOS, scientists, and scientific investigations. Critics consider this approach to be narrow in how NOS is conceptualized and contextualized. However, unlike the forced-choice instruments, the open-ended nature of surveys and interviews leave opportunity for emergent ideas about NOS. Interviews that follow survey responses enable additional probing for examples and explanation of ideas. There is power in asking questions such as "How do you think scientists use creativity in investigations? Can you provide an example?" and "Why do you think scientists sometime come to different conclusions even when they are looking at the same data, such as with explaining dinosaur extinction? Can you think of another example when this might happen?" Multiple questions that target the same NOS areas result in rich information of how the respondent conceptualizes NOS. The power in this approach is that the words, ideas, and contexts come from the person responding. The interviews increase validity by ensuring the researchers' interpretation is consistent with the respondent's intended meaning. NOS measures such as the *Views of Nature of Science* (VNOS) questionnaire (Lederman et al. 2002), interview approaches (e.g., Carey and Smith 1993; Driver et al. 1996), and other open-response techniques also allow for identifying connections among NOS aspects such as the tentative, creative, sociocultural, empirical, and theory-laden NOS. Moreover, these techniques enable the use of a variety of science contexts and situations.

Measurements of NOS as epistemic activity include observations and interviews (e.g., Carey and Smith 1993; Sandoval 2005). Written instruments have also been used that require respondents to design an investigation or reason through data in the context of a scientific episode or vignette. These approaches are based on the assumption that NOS is represented through epistemic and social acts of doing science. Observations of students and scientists conducting investigations are considered representations of their NOS abilities. Again, this view and measurement approach is in contrast to the afore-described measurements that assume NOS as conceptual knowledge.

Regardless of the approach, measurements of NOS knowledge are framed by how the researcher conceptualizes NOS. NOS conceptualization, measurement methods, and interpretation should be grounded in what is appropriate for the audience. Much of the research in science education that involves the measurement of NOS knowledge focuses on the K-12 population, including teachers and students. However, measures for scientists, preschool children, college students, and adults have also been developed.

Measurement of NOS Within Instruction

Based on the view that NOS-related learning outcomes are cognitive in nature, asking students to articulate their knowledge and understandings about NOS can serve to assess student attainment of these learning outcomes. Equally important, evidence pertaining to the assessment of NOS-related learning outcomes could be generated from asking students to *reflect* on their actions as they engage with science learning experiences. Students' reflections make the latter approach clearly distinct from attempting to infer student NOS understandings from observing those actions.

Realizing that NOS is a cognitive learning domain serves to demystify the measurement of student learning about NOS. This realization makes available to science teachers a variety of formative and summative assessments that could be used to gauge student progress toward achieving and achievement of NOS-related learning outcomes, respectively. Additionally, this perspective allows drawing on a host of science learning experiences as contexts to measure student NOS understandings. These experiences include exploring scientific theories and concepts, inquiry-based investigations, discussions of socio-scientific issues, and engagement with science-related texts and narratives. The latter materials include historical case studies (see, e.g., *The Pendulum Project* by Michael Matthews), popular science writings and media productions (e.g., popular science books, science-related news reports and press releases, documentaries), and scientific publications. Regardless of the context, instruction and embedded NOS measurements must be purposeful and explicit.

For example, students might conduct an investigation of animal behavior using crickets. Teachers can ask students to identify observations and inferences as they generate questions to investigate. They can be required to include distinctions between their observations and inferences in their reports. Likewise, historical case studies are intriguing for students and also opportunities for formative assessment measures. For instance, after examining a narrative on John Snow and the Broad Street pump, tenth-grade students could be asked, "How did Snow identify the source of contamination by observing the scatter dot maps of deaths associated with the 1854 cholera outbreak in central London?" Student responses could help gauge their understanding of the role of theory in guiding data collection and interpretation. Within the context of socio-scientific issues, such as the development and use of genetically modified foods, teachers can ask students to articulate the positions, beliefs, and values (economic, aesthetic, cultural, etc.) of the players involved with such issues. To measure students NOS views with respect to the social and cultural embeddedness of science, students could be asked, “To what extent did the beliefs and values you attributed to scientists play a role in their position? Defend your answer with evidence generated from examining the published articles about the debate.”

The important consideration with in-class measurements of NOS knowledge is to be purposeful and explicitly ask students for their ideas and to explain connections between the science they are doing or learning about and how it represents various features of NOS. In contrast, the alternate view that NOS is exemplified through epistemic and social dynamics of scientific practices infers NOS “abilities” based on observed behaviors. In-class measures from this perspective also include engaging students in scientific investigations, historical and contemporary case studies, and socio-scientific debates. However, rather than explicitly drawing students’ attention to NOS connections and requesting explanations of those connections, the teacher seeks evidence that students can design and conduct appropriate investigations, critically reason through data, and generate as well as evaluate arguments. The expected learning outcomes from this approach must be distinct from those described above for NOS cognitive outcomes, as the research literature clearly demonstrates the ineffectiveness of simply engaging students in doing science for developing conceptions of NOS knowledge (Lederman 2007).

Cross-References

- ▶ Epistemic Goals
- ▶ Epistemology
- ▶ Nature of Science, Assessing of
- ▶ NOS: Cultural Perspectives

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NOS: Cultural Perspectives

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Keywords

Culture, science and religion

Science is essentially a cultural enterprise, one that shapes and is shaped by the broader culture. Conceiving the scientific enterprise as a culture in its own right affirms the role of assumptions and social norms in producing and validating its core knowledge claims and practices. Viewed from this angle, the special aspects that make science what it is are the sets of practices and norms that are inseparable from the knowledge they produce. The boundary that separates science from nonscience is not one of absolute demarcation, but of “family resemblance” (Irzik & Nola, 2014) of knowledge, practices, and social norms, as defined by the community of practitioners working within scientific subfields. In the last three decades, growth in philosophical analyses of various disciplines (chemistry, biology, geology) and in the field of science studies has produced rich accounts about the diversity of epistemic norms and practices that characterize these fields, rendering broad and decontextualized descriptions of scientific methods and practices vacuous.

As a highly specialized sphere of activity, science is not isolated from the rest of the culture in which it is practiced. Oftentimes, it is nourished by the values of that culture. For example, the rise of "Western science" in Europe and the subsequent industrial revolution in the 1700s took place in countries that were open to ideas that did not need to be sanctioned by religious authorities (which varied at the time in their degree of centralization). A certain level of intellectual freedom and state patronage seemed essential for promoting scientific and technological growth. There were religious and political reasons for supporting the rise of science more rapidly in countries that underwent religious reformation, in a way to counter others that were dominated by the Catholic dogma. This was not a case of a Christian versus a non-Christian culture, but that of a Christian culture that allowed a certain degree of openness and freedom of thought that is conducive to innovation. The ensuing age of Enlightenment in the seventeenth century resulted in economic prosperity and power that was instrumental in enhancing military capacity, supporting trade, and expanding colonial interests. Read from our current-day perspective, these developments also resulted in creating a culture of exploitation and an increasing concern about pollution and the impact of rapid development on the human condition. Therefore, a scientific culture cannot occur in vacuum or develop without impacting the material culture as well as the values and worldviews shared by the broader culture in which it exists (Jacob 1997).

From a cultural perspective, therefore, domains of scientific activity can be enabled or constrained by the surrounding cultural forces whether they are ideological, political, or religious. Galileo's work on pendulum motion was not entirely motivated by his personal curiosity but was nurtured by the social and political agenda of improving the accuracy of time measurement and solving the problem of longitude determination (Matthews 2000). Just as scientific research can be enhanced by the societal temperament of the time, it can also be hindered by it. In some cases, areas of research get stalled due to ethical concerns (such as human cloning), other times through restricting funding due to perceived importance and societal prejudice (as in the case of AIDS research in the 1980s). Ideological and political agendas are additional factors that can alter what research is permissible. The former USSR's censoring of genetics research resulted in losing advantage on that front and led to the persecution of scientists working in that field. Similar shifts away from working with scientific ideas seen as threatening or contradicting religious values espoused by the majority population can be found in some countries, but this effect is typically compensated for by a stronger research emphasis on topics perceived to be neutral or compatible with local religious and social values.

There is no question that religious thought infiltrates cultural worldviews and plays a key role in shaping perceptions toward the nature and meaning of scientific knowledge, often defining the relationship between science and religion. In the early days of modern science, the religious worldview motivated scientific activity as a way to understand the "mind of God." As Western science matured and refined its methodologies to rely on purely naturalistic explanation, philosophers, scientists, and theologians have engaged in a fervent effort to characterize the relationship between modern science and religion. The characterization of this relationship has often reflected a continuum of beliefs even by adherents to the same religion. For this reason, the relationship between science and religion cannot be reduced to broad generalizations, as it typically reflects the interpreters' views of the nature of religious texts relative to their elucidation of the nature of scientific knowledge. In other words, there is no monolithic interpretation that represents the views of one religious group regarding the relationship between science and religion. Furthermore, the relationship between science and religion is always contextualized in that at every stage in history, it has been explored from the perspective of the goals and methods of the science practiced at the time and extant religious worldviews.

In theistic religions, especially in Christianity and Islam, positions can be found on all sides of the spectrum. Distinctions between science and religion are usually argued on the basis of the methods of exploration used and nature of evidence used in both domains. Scholars from various Christian and Islamic traditions (traditions whose adherents have contributed in one way or another to the history of modern science) have used strands of arguments that result in three different types of conclusions. Science and religion are seen as (1) separate fields that do not overlap in terms of goals and methods, (2) reconciliatory, or (3) antagonistic. There is no united view that represents all Christian or Islamic sects. Taking key paradigmatic changes in scientific theories (Copernican revolution, Darwinian revolution) as examples, it can be seen that even the official views of one church, Roman Catholic, change over time in significant ways (e.g., position regarding the Galileo affair or Darwinian evolution) though not always in a timely fashion.

It has been argued, however, that there are basic differences between Christianity and Islam in their views of the relationship between science and religion. In Islam, the Quran as a holy text cannot be changed and all evidence is in service of this text. Studying nature is a means to help humans discover God and is not an end by itself. Western thought, however, presumes a direct relationship between mind and nature. God helps humans discover nature or does not play a role in this process. In Islam, nature is the bridge between humans and God, while in Western thought God may be the bridge between humans and nature (though not from the perspective of agnostics or atheists) (Dagher and BouJaoude 1997).

To illustrate the diversity of views regarding the relationship between religion and science, the next few paragraphs describe the positions of Islamic scholars, some of whom are practicing scientists themselves. As is the case in other religions, the scholars' immersion into scientific practice does not necessarily lead them to similar conclusions regarding the nature of the relationship between science and religion.

One view holds that the Quran as the only source of all scientific knowledge. It is promoted by Maurice Bucaille (1979) who advocated the theory of the "miraculous scientific content" of the Quran known as I'jaz. The basic principle of Bucaillism is that the Quran is the source of all scientific knowledge, which can be discovered through the interpretation of Quranic verses. Similarly, the theory of the miraculous scientific content postulates that all scientific knowledge could be acquired from passages in the Quran and that verses from the Quran can be predictions of specific scientific theories. Both views, however, are criticized because the so-called predictions are "retrospective" discoveries in that they go backward from the actual discovery to finding one or more Quranic verses that could be used to support the actual discovery. More importantly, these views, if taken seriously, would open up the Quran to falsification. It is well known that science is an ever-changing body of knowledge. Consequently, a scientific theory that is falsified based on new scientific evidence but has been supported by a verse from the Quran could lead to serious conflict.

A different view of the relationship between science and Islam is presented by Seyyed Hossein Nasr, an Iranian scholar, who rejects the attributes of modern secular science and suggests that these attributes have led to the collapse of the scared view of the universe and to environmental and nuclear disasters. As such, Nasr is considered by many to be the founding father' of Islamic environmentalism. According to Nasr, Islam has the important role of reintroducing the sense of the sacred in modern Western science and integrating religion and ethics with science rather than relegating these to policy decisions, ideas that are shared by Ziauddin Sardar, another Islamic scholar. These ideas, however, are criticized by many on the basis that they are Islamic but cannot claim to characterize modern science.

A third view of the relationship between science and religion from an Islamic perspective is attributed to Mohammad Abdus Salam, a devout Muslim, who won the Nobel Prize for physics with others in 1979. Abdul Salam's ideas focus on the complementarity of science and religion and the total separation between the spiritual and the physical world. According to him, science helps us to understand the physical world, while religion helps us understand the spiritual world. Abdus Salam is also known for advocating self-governance and total independence of science, ideas that have received much criticism because they portray science as an independent sphere of knowledge that should not be scrutinized by society and scientists as moral beings who hold the interest of society to heart.

What constitutes science according to Islam is not easy to discern because of the variety of views about scientific knowledge. What is important to highlight in relation to the broader culture is that religiosity and not religious affiliation seems to drive thinking about the relationships between science and religion. Evolution is a case in point. Evolution is part of the science curriculum in Egypt, in which the majority of the population is Sunni Muslim, and in Iran, in which the majority are Shiite Muslims. However, evolution is not part of the curriculum in Saudi Arabia whose population is almost totally Sunni Muslims and in Lebanon in which the population is divided almost equally into Christians, Sunni Muslims, and Shiites. The situation described above is not restricted to Islamic countries in the Middle East. Social controversy centered on Islamic creationism is increasing in Europe. Likewise, social controversy over evolution in the USA continues to be prevalent in certain Christian circles, causing evolution education to become a significant political issue.

In cultures that adhere mainly to nontheistic religions, such as Hindu or Buddhist traditions, the relationship between religion and science is more fluid. This is attributed to the pluralism that characterizes Hindu spirituality: "It is a holistic tradition that does not distinguish entirely between apparently conflicting principles, such as the one and the many" (Dorman 2011, p. 598). The Hindu tradition sees in science a legitimate but incomplete way of knowing. In the broader Hinduism cultural worldview "science, philosophy, and religion all blend together" (Dorman 2011). While this did not interfere with the pragmatic endorsement of Western science by the Hindu culture, the adoption of science has not entailed a whole-hearted acceptance of the scientific spirit or the metaphysical commitments and duality underlying Western science.

According to Raman (2012), Hindu, Islamic, and other postcolonial scholars sometimes point to Western science as an instrument that destroys local cultures and warn about the "hegenomic and all-devouring nature of the change ushered in by science, technology, and the globalization of English and Western lifestyles" (p. 568). These challenges, faced by many developed and developing countries, are considered to be "significant and non-trivial. Indeed, they are among the difficult challenges facing all peoples" (Raman 2012, p. 568). Concerns about these issues have fueled much discussion in the science education community. Implications to science curriculum and instruction have mostly focused on different proposals for bridging rather than replacing students' folk knowledge or traditional ways of knowing by attending to the ethnic, cultural, and linguistic aspects involved in science learning.

This discussion about cultural perspectives pertaining to nature of science highlighted some of the social, political, and religious factors that shape how science is perceived. It presents a survey, albeit incomplete, of ideas written about this topic. More attention was dedicated to the role of religion, given that in some regions of the world, perceived conflict between scientific theories and religious views has resulted in altering the content of the science curriculum. Details were provided on how scholars interpret the relationship between Islam and science to demonstrate the diversity of views that exist on this topic. Similar diversity can be expected to be found in other religions/religious frameworks as well.

The ways in which science influences culture and is influenced by it continue to frame many of the discussions in science education. Indeed, aspects of scientific knowledge and technology that conflict with traditional ways of knowing or political agendas, threaten existing ideologies, challenge religious or cultural worldviews, or pose new ethical dilemmas are bound to influence what and how science is taught. The ways in which such conflicts are addressed by a nation's science education policies and practices will inevitably have broad and far-reaching consequences on the scientific literacy of its citizens' and their ability to compete in a global economy.

Cross-References

- ▶ Biology, Philosophy of
- ▶ Chemistry, Philosophy of
- ▶ Cultural Imperialism
- ▶ Cultural Influences on Science Education
- ▶ Earth Science, Philosophy of
- ▶ Epistemology
- ▶ Multiculturalism
- ▶ Religious Education and Science Education
- ▶ Science Education in the Non-West
- ▶ Science Studies
- ▶ Scientific Values
- ▶ Worldview

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Observation

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Keywords

Induction; Scientific method; Theory; Theory-driven; Theory-laden

Careful and systematic observation has long been recognized as an essential part of scientific investigation and a key element in scientific theory building, although views about the nature and status of scientific observation have undergone substantial change in recent years.

The traditional image of science asserts that observation provides a secure base of facts from which knowledge can be derived. It further asserts that the scientific endeavor begins with observation. Both these assertions are suspect. The supposed security of scientific observations rests on the assumption that human observers have direct access to the properties of the external world, that is, nothing enters the mind except by way of the senses and that the mind is a tabula rasa on which our senses inscribe a true and faithful record of the world. In other words, observations are independent of the opinions and expectations of the observer and can be confirmed by direct use of the senses by any other observer. When Friedrich Nietzsche (1906/1968) states that "everything of which we become conscious is arranged, simplified, schematized, interpreted through and through" (para.477, p. 463), he is making the key point that we interpret the sense data that enters our consciousness in terms of previous experiences (and the sense we have made and continue to make of them), prior knowledge, beliefs, and expectations. Because it is dependent on the observer's existing knowledge and understanding, observation cannot be taken as necessarily indicative of the true state of affairs. Rather, it is a view of the world through a particular lens, that is, a particular way of looking at the world. When we acquire new knowledge and understanding, we open up new ways of seeing and explaining the world.

The key to scientific observation, as distinct from simple everyday "looking at things," is a sound theoretical frame of reference on which scientists agree. In consequence, scientific observers have to learn how to make sense of what they see in terms of accepted theory, especially when deploying one of the many observational instruments used by scientists. Michael Polanyi (1958) makes this point superbly in his graphic description of a medical student struggling to make sense of X-ray photographs:

> He watches in a darkened room shadowy traces on a fluorescent screen placed against a patient's chest, and hears the radiologist commenting to his assistants, in technical language, on the significant features of these shadows. At first the student is completely puzzled. For he can see in the X-ray

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> picture of a chest only the shadows of the heart and the ribs, with a few spidery blotches between them. The experts seem to be romancing about figments of their imagination; he can see nothing that they are talking about. Then, as he goes on listening for a few weeks, looking carefully at ever new pictures of different cases, a tentative understanding will dawn on him; he will gradually forget about the ribs and begin to see the lungs. And eventually, if he perseveres intelligently, a rich panorama of significant details will be revealed to him: of physiological variations and pathological changes, of scars, of chronic infections and signs of acute disease. He has entered a new world. He still sees only a fraction of what the experts can see, but the pictures are definitely making sense now and so do most of the comments made on them. (p. 101)

Of course, the X-ray pictures have not changed at all. What has changed is the observer (in this case, the medical student) and the observer's ability to interpret observations using particular theoretical knowledge. It is knowledge (concepts and theories) that enable us to make meaningful, significant, scientific observations. As N.R. Hanson (1958) puts it, "there is more to seeing than meets the eyeball."

The inductive process outlined in the traditional view of scientific method requires the assembly of all relevant observations and information, from which a generalization will eventually emerge through logical analysis. How, one might ask, does an innocent and unbiased observer know what is relevant and, therefore, what to observe? Observation, especially scientific observation, is a selective process and so requires a focus of attention and a purpose. An observer needs an incentive to make one observation, rather than another. As Peter Medawar (1969) puts it, "We cannot browse over the field of nature like cows at pasture" (p. 29). Making a scientific observation presupposes a view of the world that suggests particular observations *can* be made and are *worth making* – i.e., they are of scientific significance. In other words, scientific observation is neither innocent nor unbiased. It is not "objective" in the sense that some school science curricula imply. Rather, it is purposeful, theory dependent, and theory driven. In practice, some view of the world (some theoretical perspective) *precedes* observation and guides it. It is simply not possible to observe things for which you are conceptually unprepared. As Hanson (1958) points out, until Paul Dirac postulated the existence of positrons, the tracks they leave in cloud chambers were not seen at all or were dismissed as mere experimental noise. When armed with the new knowledge Dirac gave them, physicists found clear evidence in those same cloud chamber experiments of the existence of positrons. Likewise, sunspots went unrecorded in Europe until Galileo's work overthrew belief in the perfection of the heavens, whereas Chinese astronomers (with no such overriding beliefs) had been recording them for centuries. It seems to follow that there cannot be a piece of absolutely indisputable observational knowledge whose meaning is not impregnated in some way by prior belief about the world. This is not to deny that science can sometimes proceed inductively, as in situations where data are obtained first and then interesting issues and problems are identified by "data mining," but it is to say that induction is also theory driven to the extent that scientists make theory-driven decisions about what counts as data, deploy theory-impregnated instruments to collect that data, and express their findings and conclusions in language that is rich in theoretical assumptions.

All observation statements employ theoretical language. Seemingly simple observation terms such as *dissolving* and *melting* are heavily impregnated with theory; observational expressions like "craters on the moon" or "solar eclipse" even more so. The quality and usefulness of observation statements depend on the level of sophistication of the theoretical language available to the observer. Without such a language, perceptions cannot be given meaning and observations cannot be recorded and subjected to critical scrutiny. What is described in scientific observations is never "pure phenomena" (whatever that might mean) but phenomena seen through the lens of particular theories. Theoretical knowledge opens up possibilities that otherwise would not exist, and as a science develops and builds new theoretical knowledge, scientists are able to generate knowledge by making new and different observations. Thus, we learn about nature, and we also learn *how* to learn about it by learning (i) what constitutes significant information, (ii) how to collect it, and (iii) how to interpret it and communicate it to others.

To summarize, scientists work within a theoretical framework that guides their actions and invests observational data with *particular* meaning. Recognizing that scientific observation is theory laden and that students may sometimes have a different framework of reference from the teacher has an important consequence for science teachers: that the skills of scientific observation have to be taught and, moreover, taught and learned within particular theoretical contexts. Two points can be made. First, it is just not possible to teach someone to observe in a way that is independent of the context in which the observation is to be made. Second, unless teachers provide extensive guidance, there can be no guarantee that students in school science lessons will observe even the readily observable. Thus, it is the science teacher's job to ensure that students perceive the world in the appropriate way – that is, the way in which currently accepted science (or the school version of it) deems appropriate. In science lessons, we are not teaching students to observe per se. They can already do that; they have been making observations for many years, since long before they came to science classes. Our responsibility is to teach them to make *scientific* observations, and for that they need appropriate conceptual understanding.

Cross-References

- ▶ Constructivism
- ▶ Context of Discovery and Context of Justification
- ▶ Empiricism
- ▶ Models
- ▶ Science Studies

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Online Inquiry Environments

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Keywords

Online learning environments; Technology and science education research; Web-based science inquiry environments

Introduction

Online science inquiry environments are designed around the unique affordances of the Internet as a medium to facilitate inquiry. The design of such environments acknowledges the multifaceted aspects of science as a cognitive, social, and cultural endeavor through which humans seek to systematically examine and understand the natural world around them. Online inquiry refers to the use of online resources to engage in the practices of and gain knowledge about science. The main distinguishing characteristics of online science inquiry, as compared to other forms of inquiry, include the reduction of spatiotemporal limitations (i.e., fixed locations or set time limits) that might otherwise constrain access to information and communication, access to expert databases and public resources, and increased opportunities for personalizing and customizing learning experiences. These affordances are further enhanced when coupled with recent technological improvements such as mobile computing and advanced data-mining techniques.

Such environments may be employed in any combination of face-to-face, online only, or blended learning, with interactions occurring synchronously and/or asynchronously within the environment. Finally, despite the mediation of technology, the teacher remains an important learning partner in these environments, with the challenging role of orchestrating activities and interactions, monitoring student ideas, and intervening strategically (i.e., with mini lectures or small group discussions) to ensure effective learning.

While the Internet offers many unique affordances for learning, the underlying goal of online science inquiry environments is fundamentally aligned with other powerful learning environments developed by science educators. Research has shown that successful learning environments promote deep understanding, knowledge integration, and critical thinking, embed assessment and feedback mechanisms, and create communities where learning can be fostered (Bransford et al. 1999). Thus the term "online science inquiry environments" does not refer to any digital resource on the Internet, but is reserved for those environments that offer a carefully scaffolded virtual space where learners meet to pursue common learning goals. As online inquiry may require greater levels of self-regulation than other forms of instruction (particularly if students are working from home), metacognitive supports, included to help learners understand the task, monitor and reflect on their progress, is a common characteristic of online science inquiry environments (Quintana et al. 2005).

Online science inquiry environments are rooted in an understanding of science learning as a multidimensional, constructivist, and profoundly social endeavor. Like other forms of science inquiry, they seek to help learners pose meaningful questions; formulate hypotheses; collect, interpret, and explain data; and engage in epistemic practices that will help them gain an appreciation of the nature of science. Like other powerful inquiry methods, online environments are guided by the importance of sense making, providing multiple representations of scientific concepts, scaffolding student learning, making thinking visible, articulation, reflection, and self-regulation (Slotta and Linn 2009). To help explain what makes online inquiry environments distinct from other forms of science inquiry learning, the following sections will discuss their characteristics, using two online science inquiry environments – WISE and STOCHASMOS – as examples.

Increased Authenticity

Online science inquiry environments can take advantage of the wealth of Internet resources to make learning more authentic, using real-world problems to engage learners in complex scientific reasoning, promote active learning, and increase motivation. For example, the Web-Based Inquiry Science Environment (WISE), one of the earliest online inquiry platforms (Slotta and Linn 2009), engaged students in the Deformed Frogs controversy, where they inquire about a real problem of frog malformations using current Web materials and a variety of inquiry tools. Deformed Frogs was a science inquiry curriculum unit written in partnership with scientists who were actively investigating that issue. Research by the WISE team has shown that such environments foster a grounded and evidence-based understanding of scientific concepts and support argumentation and reflection.

Guided yet Flexible Learning

Online inquiry science environments can provide technology-based scaffolds for learning activities while still allowing learners to explore rich, Web-based resources. One example of the application of such a capability can be seen in the support of evidence-based reasoning. As students use the Internet to locate data in support of their arguments, they can also benefit from technology scaffolds that guide them through a particular task structure. For example, the STOCHASMOS platform (Kyza et al. 2011) scaffolds students in reflecting and making grounded connections between data and interpretations using a data capture tool which automatizes the documentation and transfer of evidence from any webpage or other software to an online reflective workspace. This allows students to focus on the conceptual aspects of the task and allows freedom in exploring Web resources while at the same time anchoring these actions back to a process of reflective inquiry. Online science inquiry environments differ in how they support flexible learning. WISE uses a guided inquiry approach, providing an "inquiry map" that students follow, launching a succession of inquiry tools and activities. STOCHASMOS depends on the learners' adoption of a problem-based scenario with concurrent use of the reflective workspace to guide their reasoning with data. Other technologies are designed to serve as a metacognitive layer intended to guide online activity, such as the Artemis tool, which supports the organization of online information; Symphony, which guides learners through an inquiry cycle; and the Digital Idea Keeper which supports the organization and planning of online inquiry (Quintana et al. 2005).

Enhanced Social Interaction

Another characteristic of online inquiry environments is their capability of promoting and enriching social interactions. Environments such as WISE and STOCHASMOS aim to support collaboration in the classroom, emphasizing learning from and with peers. However, such environments also make use of synchronous and asynchronous tools that allow communication with students from home or disparate geographical locations. For example, STOCHASMOS includes tools to share ongoing work between groups of students who, in turn, can provide synchronous and asynchronous context-based feedback to their peers. Such work can help focus and structure students' online interactions, providing unobtrusive guidance while students still remain in control of their learning process. The use of such prompts can also support metacognitive awareness and reflective thinking in such collaborative exchanges.

Embedded Assessment and Educational Data Mining

The opportunities for data-driven assessment and adaptive feedback are important capabilities of online science inquiry environments, which typically collect automatic data logs of learners' activities that allow for the construction of numerous forms of feedback and assessment. For example, WISE can provide immediate feedback on some assessment items but also provides well-organized reports to teachers and supports their evaluation and feedback to students. Other systems employ on-demand reports that provide enhanced and ongoing assessment information to teachers and to students. Research is currently exploring the use of artificial intelligence techniques to support the personalization of learning based on user modeling, providing customized materials, adaptive support, or notifications to the teacher to take action.

Teacher Adaptation of Learning Environments

One of the advantages of engaging with Web-based science learning is the ease with which teachers can engage in designing or adapting such environments. Web-based authoring tools have reduced the need for sophisticated technological skills to create scaffolded learning environments in science through the use of such tools as content-management systems and wiki technologies. For example, both the WISE and STOCHASMOS authoring platforms allow teachers to author online learning environments. While it remains a challenging process for teachers to become Web-based learning designers, existing systems provide authoring supports that help scaffold epistemologically appropriate designs, as well as the ability for teachers to customize existing designs from the library of projects (Slotta and Linn 2009). Additionally, the process of engaging teachers as designers can create opportunities for professional development.

Challenges and Opportunities

To take full advantage of the affordances of the online science inquiry environments, teachers need to invest time and effort in developing the relevant technological pedagogical content knowledge. Even though the online nature of such technologies may make it somewhat easy to get set up and going in the classroom, a considerable investment is required to understand how to use such technologies most effectively and especially how to balance computer-based and human scaffolding (Slotta and Linn 2009). As new forms of mobile and ubiquitous computing gain acceptance and technologies become interoperable, online science inquiry environments will likely converge with other technologies to create more seamless learning environments that cater to the needs of the learners. Such environments could serve to transcend the traditional boundaries between formal and informal or online and offline learning by supporting learning and communication across space and time. Finally, to help researchers take full advantage of every new step forward, open-source initiatives can help create synergies and promote exchange and co-development (Slotta 2010).

Cross-References

- ▶ Digital Resources for Science Education
- ▶ Inquiry, Learning Through
- ▶ Scaffolding Learning

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Online Media

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Accessibility; Collaboration; Customization; Educational media; Enabling technologies; Information and communications technology; Information literacy; Internet; Media convergence; Online citizen science; Open educational resources; Participation; Personalization; World Wide Web

Introducing Online Media for Informal and Formal Science Learning

The past 35 years have seen an unprecedented period of growth in the development and use of online media for informal and formal science learning (Holliman and Scanlon 2004). These are educational media where the computational power of computers and the interconnectedness of communications technology converge. As such, these are media that are networked, e.g., via the Internet, intranets, or Short Message Service (SMS). In simple technical terms, networking requires interconnectedness and interoperability between computing devices that can be located in multiple locations and different time zones. This involves digital information that can be efficiently stored, searched for, and then retrieved and shared.

Developments with online media have profound implications for the accessibility of all areas of knowledge, not least for informal and formal science learning. Online digital information, such as school intranet pages, can now be "retrieved" from a number of geographically distributed locations via a uniform resource identifier (URI; a codified address that points to a resource on the World Wide Web). This information is sent to the user, such as a teacher, parent or guardian, school-age pupil, university student, or informal learner, via a network. Applications (such as a web browser) hosted on compatible devices (including personal computers, personal digital assistants (PDAs), and mobile phones) then "read" and "reformat" this digital content (e.g., the title of the school intranet page always goes in the middle at the top; the accessibility options directly underneath, left aligned; and so on).

This entry provides an initial definition of online media for informal and formal science learning. Three key trends in the current (2012) digital landscape will then be outlined: media convergence, accessibility, and collaboration and participation. The entry will draw on examples to illustrate some of the concepts being used to analyze and describe educational media and their uses in formal and informal science learning.

There is one note of caution. Educational media can be sold as commercial products that are developed and promoted within a competitive marketplace. It follows that, as a prospective consumer, citizen, and learner, the reader needs to retain a critical attitude when assessing the relative merits of educational media.

Finally, for this introduction at least, the examples discussed in this entry are necessarily small in number, and they are only briefly described. What follows is an attempt to map what is a rapidly developing landscape, technologically, socially, economically, politically, legally, and culturally. No entry that discusses online media could ever claim to be future proof. It will be up to the reader to apply these ideas, seek out new ones, locate additional examples, and critically engage with relevant academic literature.

Media Convergence and the Pervasive and Ubiquitous Nature of Digital Technologies

Convergence is a significant trend that has considerable relevance for how online media and educational resources are accessed and used by formal and informal science learners. In a technological sense, media convergence is all about integration and interoperability, the coming together of computing networks, information and communication technologies, and digital forms of information that are inherently adaptable, delivered via "intelligent" platforms, applications, and devices. From an end user's perspective (e.g., those seeking to learn new skills, competencies, and scientific knowledge with the aim of applying this learning through online conversations, participation, and collaborative contributions), media convergence involves digital technologies that encode and decode multiple streams of, in this case, science content. This can involve linked and aggregated text, galleries of still images with the opportunity to upload and tag further images, moving pictures (such as a virtual field trip), digital simulations, self-pacing interactive tutorials (that can be structured to provide automated feedback, advice, or comments), sounds, music, science-based computer games, access to remote experiments or equipment, opportunities to input and analyze data "on the move," or any combination thereof. This content is mediated through one or more devices and platforms of the end user's choosing, such as a mobile phone, tablet, laptop, desktop computer, or personal digital assistant (PDA). These media can then be customized and consumed “automatically” via feeds that match the user’s personalized profile on the device(s) of their choice.

As a result of the convergence of computers with communications technologies, teachers, parents or guardians, and informal and formal learners with network access have opportunities to teach and learn about scientific information that is relevant and useful to them, wherever and whenever they are, and on an increasing range of computing devices. To illustrate the point, imagine an idealized (and simplified) scenario where a university student (let us call him Fred) is on his way to an astronomy lecture on a Monday morning. Fred travels on the bus from his home to the campus watching (and listening through headphones) to an archived television show about astronomy on his smartphone. He checks the website associated with the television series and texts an answer to a competition announced during the episode as entries close at lunchtime that day. On the same journey Fred responds to a text message from a fellow student asking him to send them details of where the lecture will be archived as they are unwell and cannot attend. Fred gets to the lecture hall and checks his emails before the lecture starts. As the lecture finishes he tweets details of an open access repository where one of the academic papers that the lecturer recommends is hosted. After the lecture, he goes to the university library where he checks the discussion forums of a citizen science astronomy project that he has been contributing to. This is all achieved through a networked “post-desktop” computing device called a smartphone, but without what we used to think of as a phone call being made. This is pervasive, ubiquitous, personalized, and mobile computing where the distinction between formal and informal learning is blurred and where the student – Fred – is both learning about and contributing to astronomy within the course of a couple of hours, all of which is mixed in with leisure activities.

Of course, to become a pervasive and ubiquitous digital hardware, tools and technologies have to be flexible, adaptable, intuitive, and useful. Fred provides us with just one example of this. The widespread adoption of these technologies emphasizes the point. These technologies are profoundly social and have been designed with a good range of uses and users in mind.

It should come as no surprise, given the example described above, that the processes that facilitate media convergence are shaped by social practices and cultural values, and vice versa. The success of online media is reflected in the changes in how people access and use information, and by the blurring, in places, of the distinction between some aspects of formal and informal learning. We use digital technologies to learn about the sciences, politics, sport, and so on while also contributing, through the use of these technologies, to the public discourse about these subjects. Where once people had opportunities to collate and filter scientific information via various “traditional” communication channels, such as textbooks, printed encyclopedias, and science documentaries on television, now digital technologies are also playing an important role. In effect, well-designed educational media enable different routes to learning that can combine in powerful ways, e.g., through narrative, interactive, adaptive, communicative, and productive forms (Laurillard 2002). Indeed, the reader is contributing to this trend by reading this entry in an online encyclopedia and accessing other related content through hyperlinks. Furthermore, if there is a wish to extend, revise, or delete this entry, some media forms (e.g., Wikipedia) would allow the reader to do this, thus extending the learning experience.

Accessibility: Open and Easy Access to Educational Resources and Scientific Information

The second theme that we consider in this entry is accessibility. This broad theme can be subdivided into at least two important subthemes:

- Open and easy access to scientific information

- Accessibility of educational resources to ensure that they are designed for end users with different needs

Open and Easy Access to Scientific Information

Routine and continued access to reliable and credible scientific knowledge (in conjunction with the skills and competencies to filter, analyze, and respond to it) is crucial for informal and formal science learning. Concepts such as the “digital divide” illustrate that a lack of routine access to information, scientific, or otherwise can reinforce preexisting structural inequalities and hamper science learning.

Access to scientific information can be influenced by a number of factors, particularly financial constraints, which can be compounded by the fact that one piece of hardware is rarely considered to be sufficient in the digital age. Furthermore, hardware, software, and network infrastructure need to be upgraded over time, adding to the overall financial cost of accessing scientific information. In addition to financial considerations, the ability to connect through secure, networked infrastructure is vital to ensure that users can access educational resources with confidence and share data and information quickly and effectively.

However, financial constraints are only one hurdle, and the proliferation of digital forms of knowledge requires skills (and continued training) in order to effectively navigate through the digital ecosystem. In other words, formal and informal learners need to develop systematic information literacy skills that enable them to sort the “wheat from the chaff” and to be able to assess and respond to information and resources that are considered credible and reliable (Weiner 2010) . This can be a particular challenge for informal science learners if they have little or no formal training in how to systematically source credible scientific information, while formal learners need support and study time to develop, practice, and demonstrate these skills.

Another important issue that has been the subject of much attention is the denial of access to resources that can be used for educational purposes because the content is not generally available for public consumption, e.g., because it is behind a subscription paywall. Developments with open educational resources, open access to research papers, and open datasets provide alternative routes to content that can be used for educational purposes. Typically, open educational resources are made available free of charge to the user under licenses that promote reuse, and sometimes reversioning, but with certain conditions attached, e.g., a requirement that the resources are not resold for commercial purposes.

Open educational resources have become hugely popular. Open Learn – Learning Space, for example, a repository of open educational resources developed by the UK’s Open University, has been used by over 21 million unique visitors from 2006 to 2012, while the Open University resources on iTunes U have generated over 58 million downloads from 2008 to 2012. This wider trend in making educational content freely available is illustrated by the emergence of Massive Open Online Courses (MOOCs). MOOCs provide informal learners with access to educational content, but without having to formally register for a course. These developments have led to discussions about the role and purposes of higher education institutions. This is illustrated by a disaggregation of the functions that universities and lecturers provide for students: content in the form of open educational resources; support, which can be provided by lecturers and/or by peer learners; and assessment and accreditation, two functions which may be relevant only for registered learners (McAndrew et al. 2010).

Accessibility of Educational Media and Resources

Open and easy access to scientific information takes on another dimension when we consider users with special educational needs. Ensuring that users with different needs can access and use forms of online media, either directly or through the use of enabling technologies, requires a more inclusive and participatory design process.

"Design for all" encapsulates this approach. This approach has benefits for all users because the resulting hardware, tools, technologies, and resources will be more adaptable and flexible, thus facilitating user customization. All learners can benefit from well-designed educational resources, and a user-centered approach to design greatly improves the chances that end users will be able to access the same or equivalent information. In practice, accessibility issues need to be considered at each stage of the design process: initial design and planning, asset creation, asset compilation, and media output. A combination of formative and summative evaluation, involving users with different needs, should inform each stage of the design process. The information gleaned through this user-focused design process can then inform the advice and guidance that is provided to prospective learners before they begin their study, e.g., in identifying core versus optional content, requirements, activities, and assessments.

Developments with digital technologies have helped to automate some aspects of production processes, particularly around text-based resources. For example, digital information can now be provided in multiple forms. The same text can be printed, rendered as a series of linked web pages, and "screen read" as a spoken word. Resources should also be designed to allow users to decide which font size and text/background contrast they find easiest to read. These developments provide technological solutions that make the same content available in multiple forms.

Resources should also be checked to ensure that they connect effectively with different enabling technologies (e.g., screen magnifiers, screen readers, and speech synthesizers). And there are other routine procedures that producers of educational media should make available, including the production of screen-readable transcripts for audio and audiovisual resources, keyboard-accessible navigation of web pages (including keystroke alternatives to using a mouse), and the routine provision of alternative text explanations for images.

Collaboration and Participation: The Contribution of Online Citizen Science Initiatives

The third and final theme to be considered in this entry is collaboration and participation. After a brief introduction to ideas about citizen science projects that are at least partly conducted online, a typology of activities is offered for these increasingly popular activities to demonstrate the different levels of collaboration and participation that informal and formal science learners experience.

What Is (Online) Citizen Science?

Citizen science is a form of research collaboration involving both scientists and members of the public. Participants engage with scientific research projects to address authentic scientific research questions. Citizen science projects have a history that dates back at least a century, e.g., to the Christmas Bird Count, which was first organized in 1900 by the Audubon Society in the United States. Participants who engage with citizen science projects are given opportunities to learn about aspects of scientific research while also contributing and collaborating in various ways.

Online media have enabled the development of citizen science projects where data can be collected, collated, assessed, and analyzed using digital tools and technologies (Hand 2010). These projects make it possible for interested citizens (who may also consider themselves to be informal and formal learners) to participate in scientific research that is mediated by technology. They can participate within the comfort of their own home, on a field trip, and/or in a school classroom; over the summer holidays, as part of an extracurricular science club; or within scheduled science lessons.

Participants can conduct a range of tasks, e.g., collecting and submitting data and/or analyzing data that has been collected by others. A number of online citizen science projects have also developed resources for learning. Zooniverse, for example, has developed a number of educational resources that support activities within informal and formal science learning environments.

Online citizen science projects can be classified into at least three types: distributed computing projects, distributed thinking projects, and scientific discovery games.

Distributed Computing Projects

Distributed computing projects represent the earliest form of online citizen science. These projects were developed in response to the large amounts of data produced by projects, such as SETI (Search for Extraterrestrial Intelligence). In this type of activity, project organizers invite networked users to volunteer part of their computer's processing capacity for the analysis of data. Initially potential participants (e.g., citizens with a general interest in the search for extraterrestrial life) access information about the distributed computing project and the related science from the project website. Should they want to become more involved, participants download the project software usually to a desktop computer or games console. That networked computing device will automatically download and analyze small packages of data using the project software and then returning the completed work units to the original project server.

The level of interaction and participation on the part of the citizen scientists is relatively limited. However, participants in distributed computing projects have opportunities to learn about the project and its methodology and to offer resources in support on this venture. But, due to the automated nature of the analytical procedures, the levels of interaction and collaboration beyond this are limited. Participants can interact in other ways though, e.g., through online forums where they are provided with opportunities to discuss topics of interest with other citizen scientists and/or the project scientists.

Distributed Thinking Projects

Distributed thinking projects typically involve classification tasks and observational skills that cannot easily be undertaken by computers, such as pattern recognition tasks. Participant contribution is likely to begin in the same way as distributed computing projects, e.g., by learning about the research questions and methodology from the project websites. Those who go on to register on distributed thinking projects will be required to contribute on a more active, cognitive level than for distributed computing projects.

For distributed thinking projects, participants are likely to need some level of training in the required analytical tasks, e.g., engaging in learning through online tutorials. And, as with any scientific research project, due consideration must be paid to the potential for error in the analysis conducted by all participants. In some distributed thinking projects, this is minimized by giving numerous citizen scientists the same task. It is worth noting, therefore, that the results obtained by citizen scientists in these types of projects are generally comparable to those obtained by professional scientists.

One of the most popular examples of a distributed thinking project is Galaxy Zoo, where hundreds of thousands of images of galaxies have been classified by online citizen scientists. Galaxy Zoo participants have been instrumental in several important discoveries, for example, the discovery of a new type of galaxy, and have also appeared as coauthors on academic papers.

As with other types of citizen science initiatives, distributed thinking projects can lead to the emergence of online communities and collective identities, e.g., Galaxy Zoo participants refer to themselves as "Zooites." These communities often emerge entirely through online interaction where participants share information concerning the scientific aims of the project, information relating to the background science, and technical questions relating to data analysis or the downloading of software.

Distributed thinking projects have developed to the point where this conceptual idea has developed beyond single projects. For example, the success of Galaxy Zoo has inspired the development of a number of distributed thinking projects within the umbrella project known as "the Zooniverse," including (among others) Whale

FM, where participants help to track whale populations by identifying distinct whale songs; Planet Hunters, in which participants look for extrasolar planets; and Seafloor Explorer, where the participant helps to record ground cover and the number and types of animal species present on the ocean floor.

Scientific Discovery Games

Scientific discovery games are the third of the three types of online citizen science discussed in this entry. These are online games that are based on an authentic scientific problem. Participants contribute through their puzzle-solving abilities and/or spatial awareness skills. Players do not necessarily need any special scientific knowledge or gaming skills before they start to play. This knowledge can be learned through online tutorials or from other players.

One of the best known examples of scientific discovery games is Foldit, an interactive puzzle game where players attempt to elucidate the three-dimensional structure of protein molecules. Players can play individually, or within a team, and compete against one another within a points system. Protein structures that come closer to their "natural" configuration (i.e., one that requires the least amount of energy) are awarded a greater number of points.

Since its launch, a number of significant scientific breakthroughs have been made by Foldit players. For example, two teams of Foldit players were instrumental in "solving" the three-dimensional structure of an enzyme relevant to HIV infection – a problem that had confounded biochemists for the best part of decade. Players also use online forums to discuss issues related to the game and the science associated with it.

Scientific discovery games can also offer a novel form of collaboration not only between professional scientists, games designers, and interested citizens but also between citizen science players. For example, Foldit players share puzzle strategies and scripting code and help to guide new players through the rules of the game. In effect, Foldit is not just an online scientific discovery game. It is also a community of skilled games players who are willing to collaborate and share their expertise in the furtherance of cutting-edge scientific research.

Foldit provides an example of the potential of online media for formal and informal learning. The most successful Foldit players have developed expertise and gained skills and competencies in particular areas, forming communities of practice in relation to particular areas of the game. They have gained the requisite knowledge and skills to participate in this scientific endeavor through different routes, in all likelihood combining their experiences of formal and informal science learning to the point where they can share this learning and collaborate with others. If the pioneers of networked infrastructure and the early developers of digital hardware, tools, and technologies are reading this entry, they can be proud of what others can achieve individually and collectively through the power of online media.

Cross-References

- ▶ Citizen Science
- ▶ Learning Science in Informal Contexts
- ▶ Lifelong Learning
- ▶ Public Engagement in Science

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Opportunity to Learn

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Keywords

Academic engagement; Curriculum exposure

Opportunity to learn (*OTL*), a term introduced by John Carroll in the early 1960s, conveys the idea that students' school learning is a result of the time they spend engaged in learning and thus that students cannot be expected to learn if they do not have adequate time to do so (see Carroll 1963). Since its introduction, OTL has played key roles in international assessments, accountability policies, and practices and is standards-based reform. These themes are expanded below, including OTL's role in policy and practice and measurement methods.

The What and Why of Opportunity to Learn

John Carroll's model of learning offers a base definition for OTL by establishing that learning, as measured by achievement tests, is a function of the time students are engaged in learning the specific topics on which they are assessed relative to the time they need to learn those topics. The model also sets out a general set of categories that influence how much time is needed – for example, student ability and availability and effectiveness of instructional resources. OTL thus can encompass both student engagement in relevant curriculum and the sufficiency and effectiveness of such engagement (see McDonnell 1995). The concept, defined by one or both dimensions, has been used to understand and explain student performance, as a policy lever to promote equity and fairness in education, and as a tool for improving teaching and learning.

IEA's Second International Mathematics Study (SIMS) in the 1980s provides the first large-scale application of OTL to examine the extent to which differences in curriculum and instructional exposure to particular topics, rather than the ability to master those topics, might explain differences in achievement. SIMS defined OTL as instructional exposure, as gauged through curriculum analysis and surveys of teachers, and was followed by the Third International Mathematics and Science Study (TIMSS), which added video analysis of classroom practice to delve more deeply into OTL differences that could explain cross-national differences in performance.

Concurrently, policy makers, notably the United States, looked to accountability as a means for improving student outcomes. Minimum competency exams in many states in the United States, for example, required that students pass a test to receive a high school diploma, and state and federal legislation moved toward holding schools and students accountable for achieving high standards of learning. Public discussion of OTL standards soon followed. Motivated largely by fairness concerns that students not be held accountable for content and skills they had not had the opportunity to acquire, OTL standards also were intended to signal what needed to be in place to enable students to achieve higher learning standards and potentially to create a framework for monitoring and improving OTL and hence educational effectiveness. Among the proposed standards were those involving:

- Curricula and materials
- Teacher capability
- Continuous professional development
- Alignment of curriculum, instructional practices, and assessments with content standards
- Safety and security of the learning environment
- Nondiscriminatory policies, curricula and practice
- School financing

These standards expanded existing definitions of OTL to clearly reflect concerns for equality of opportunity. OTL is thought to be central in explaining and remedying the achievement gap for economically disadvantaged and minority students. Their case is supported by research documenting both the relationship between OTL and student performance and disparities in OTL associated with race, ethnicity, language, gender, and disability status, for example, in teacher qualifications, available curriculum materials, course access content, and school finances.

Finally, at the core of the OTL concept is the need for effective curriculum, instruction, and teaching to enable students to achieve rigorous learning goals. This same sentiment permeates standards-based reform, where systems establish standards for student learning and assess how well students are achieving them. Educators are charged with designing and delivering curriculum and instruction – effective OTL – that will enable students to achieve the goals and with using assessment data to improve their efforts. Analysis of OTL goes part and parcel with improvement. If students do not do well, is it because they lacked OTL and/or what aspects of curriculum and instruction were insufficient to enable students to develop the scientific understanding they were expected to achieve?

Methods for Assessing Opportunity to Learn

A variety of methods have been used to assess opportunity to learn, including teacher and student surveys, teacher logs, analysis of curriculum and instructional artifacts, observations of teaching and learning, and archival data. Most methods primarily focus on content analysis and emphasize the alignment between content that is taught and that which is assessed. For example, surveys, observations, and analysis of curriculum artifacts (e.g., lessons, text books, assignments) have been variously designed to examine whether or not specific topics have been taught (content coverage), how much instruction time each topic has received (content exposure), or the extent to which a topic is or has been a major, minor, or no priority in classroom instruction. Quality of instructional delivery, as measured by the nature of the activity in which teachers and students are engaged, and level of cognitive demand also are typical foci for OTL instruments.

For example, Andrew Porter's (see Porter 2002) content alignment methodology has been used extensively in teacher surveys describing the content of classroom instruction, content analyses of instructional materials and assessments, and indices of alignment between standards, instructional content, instructional materials, and/or assessment. The methodology uses a two-dimensional matrix composed of the topics of instruction and categories of performance expectations – or cognitive demand. Topics can vary by course, grade level, and locale and can be specified at various levels of detail, for example, force and motion, chemical reactions, kinetics, and equilibrium – or major concepts and subtopics within each. Cognitive demand categories are consistent across grades and subjects in science and include the following categories: memorize, perform procedures, communicate understanding, analyze information, and apply concepts. Instruction and the standards and/or assessments are charted relative to the matrix to indicate the amount of time spent on each topic and, for each topic, the relative emphasis given to each category of cognitive demand.

Norman Webb's (see Webb 2007) methodology, as another example, has been used to examine the alignment between tests and the standards and objectives the tests are intended to measure, but it also could be used to examine the alignment between instruction and assessment. Qualified raters work from an established set of standards and objectives and identify the standard and/or objective measured by each item or task on a given test. They also use a 1–4 scale, the depth of knowledge elicited by each item and evident in each standard or objective. Both the Porter and Webb methodologies provide summary indicators of the breadth and depth of alignment and gaps in coverage.

Other methodologies have not been directly used in science education but are potentially applicable to it. For example, the CRESST assignment analysis methodology has been used to examine the quality of OTL by evaluating the nature of the assignment's learning goals, alignment between those goals, instructional activity, assessment, and the intellectual rigor of the expected work (See Clare-Matsumura & Pascal 2003).

Use of OTL Data

Analysis of OTL can be conducted at the individual student, classroom, school, district, regional, or national levels. For example, a teacher might diagnose an individual student's learning needs by considering the student's OTL relative to his/her performance. Similarly, that same teacher may evaluate the strengths and weaknesses of her curriculum by considering the class's assessment results in light of the content and cognitive demands of the OTL students have been provided. A school, district, or state might consider equity in the OTL it provides by examining OTL by subgroup, and courts in the United States, in fact, have used such data to inform decisions on equality of opportunity. All users might consider what inferences might be drawn from the data to improve OTL and thus to support improvements in learning.

Cross-References

- ▶ Assessment: An Overview
- ▶ Curriculum
- ▶ Curriculum Emphasis

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Out-of-School Science

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Keywords

Ecological studies; Environmental education; Field trip; Fieldwork; Science beyond the classroom

Out-of-school science refers to the diverse range of activities that take place beyond the classroom. Such activities include those which take place in the school grounds, in local open spaces and parks, and further afield, often at residential centers. One major category of out-of-school science is fieldwork, a term that usually refers to the collection of data, including observations, as part of an ecological study. Indeed, traditionally, out-of-school science is often regarded as being predominantly biological in nature. However, there is a strong tradition of earth science education taking place outdoors and the physical sciences can also be taught beyond the classroom.

There is substantial evidence that under the right conditions – properly conceived, adequately planned, well taught, and effectively followed up – out-of-school science provides opportunities to develop knowledge and skills in ways that add value to students' everyday experiences in the classroom (Rickinson et al. 2004). A key issue here is the need to integrate science learning in the classroom with what takes place outdoors, a process that involves effective pre- and post-activities. Although the novelty of the outdoors may lead to memorable experiences, novelty can also significantly reduce learning as students can be distracted by new and sometimes challenging situations. The preparation, therefore, has to take account of the learner's prior experiences and needs in terms of feeling secure and safe.

Seeing scientific phenomena out of school can strengthen understanding as well as develop new knowledge. As well as experiencing phenomena in real-life contexts, students are able to develop a sense of place, that is, an appreciation of their locality and the environmental features found there. Other benefits of out-of-school science include increased appreciation of how science works and improved teacher-student relationships.

The evidence suggests that longer programs are more effective than shorter ones. At their best, residential centers may offer highly trained staff with expert local knowledge and adequate equipment for a wide range of scientific activities, such as water quality monitoring using physical, chemical, and biological techniques. An issue here is the relationship between the normal classroom teacher and the fieldwork tutor. While it is common to find teachers handing over responsibility for teaching to the tutor, collaborative teaching can have a positive impact on the learning that takes before, during, and after a visit.

A number of barriers are often cited as reasons why some teachers do not take their students outdoors including the cost, health and safety concerns, and student misbehavior. However, the fact that so many teachers do take their students beyond the classroom suggests that these barriers are not the real problems. Challenging teachers' views of what counts as science and developing their confidence in adopting new pedagogies are more likely to be the real challenge for advocates of out-of-school science.

Cross-References

- ▶ Environmental Education and Science Education
- ▶ Excursions
- ▶ Field-Based Data Collection
- ▶ Interpretive Centers
- ▶ Learning Science in Informal Contexts

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Pacific Island Ancestry

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Keywords

Cultural diversity

Pacific Islanders number approximately 13 million people residing in more than 25 island nations and territories, dispersed across the largest geographic feature on Earth – the Pacific Ocean – with growing communities of recent migrants settled mainly in the Pacific Rim nations. In many ways this population is unique among world cultural groups. The Pacific Islands were the last major area on earth to be settled by humans, the last region to be colonized by metropolitan powers, and among the last territories to undergo decolonization – with several islands remaining as non-self-governing territories (e.g., New Caledonia, Guam, and American Samoa). The Pacific Islands are also unique in terms of their degree of indigeneity and cultural continuity, having the largest proportion of indigenous people and lands held through customary land tenure, of any region of the world (Regenvanu 2009).

The Pacific Islands include enormous geographic, linguistic, and cultural diversity. Humans first moved into the region from Southeast Asia roughly 40,000 years ago, during the late Pleistocene epoch when lowered sea levels exposed land bridges across much of present-day Indonesia, joining the islands of SE Asia to the Asian mainland and joining New Guinea to the Australian continent. New Guinea islanders can claim the greatest antiquity among Pacific Islands populations, and recent archaeological research has revealed that New Guinea may be one of the oldest sites in the world for plant domestication and the development of agriculture (Denham et al. 2004).

Around 4,000 years ago, new technologies of long-distance seafaring enabled groups of people on and around Taiwan to expand southward and then eastward across the island archipelagoes of present-day Philippines and Indonesia and to settle along the coastal areas of the already-inhabited islands. Speaking Austronesian (or "Malayo-Polynesian") languages, this human expansion reached the eastern limits of the earlier settlements by about 3,000 years ago (Kirch 2010). Subsequently, Austronesian-speaking seafarers sailed into the remote Pacific, eventually settling islands throughout the vast areas of the "Polynesian Triangle" (with apices at Hawaii, Easter Island, and New Zealand) and "Micronesia" (the small islands of the Marianas, Carolines, and Marshalls north of the equator). The settlement of the vast Pacific Ocean, using indigenous knowledge of navigation and

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seafaring, must rank among the greatest achievements in human exploration and migration. Austronesian speakers, embodying some 1,200 languages distributed from Easter Island to Madagascar, were the most widely dispersed language family in the world, prior to the colonial expansion of English.

Since the Pacific War, islanders have migrated increasingly to metropolitan destinations, largely following the former colonial spheres of control, with the commonwealth-affiliated South Pacific Islanders moving to New Zealand and Australia and US-affiliated North Pacific Islanders moving to the United States. Auckland holds the distinction of being the largest Polynesian city in the world, while Hawaii and the US west coast are home to growing communities of Samoans, Chamorros (from Guam), and other Micronesian islanders. The Pacific Islander diaspora is creating vibrant new communities abroad while maintaining a sense of cultural identity and continuity through dance and other performance arts, tattoo, family celebrations, language maintenance, and social and economic exchanges with their home communities in the Pacific Islands.

Cross-References

- ▶ Asian Ancestry
- ▶ Black or African Ancestry
- ▶ Cultural Influences on Science Education
- ▶ Cultural Values and Science Education
- ▶ Latino Ancestry

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Paradigm

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Keywords

Exemplars; Incommensurability; Problem solving; Scientific revolutions

Thomas S. Kuhn introduced the notion of “paradigm” into the philosophy of science to describe the consensus within a given scientific community based on past achievements that members of the community held as exemplary and thus on how to model future research on these achievements. In his monograph The Structure of Scientific Revolutions from 1962 (2nd edition with a postscript from 1970; for detailed accounts of Kuhn’s philosophy, see, e.g., Hoyningen-Huene 1993 or Andersen 2001), Kuhn described the development of science as successive periods of cumulative normal science separated by noncumulative revolutions.

According to this account, normal science is dependent on a paradigm in the form of a set of received beliefs that marks out what the acceptable research problems are and what acceptable solutions to these problems must look like. Yet some of the scientific problems defined by a paradigm may eventually turn out to be unsolvable within the framework of the paradigm, what Kuhn calls anomalies. If these anomalies cannot be resolved, they may cause a crisis in the scientific community, and in some cases this crisis eventually leads to a scientific revolution, also called a paradigm shift. The paradigms separated by such a revolutionary divide will in some areas be so different that the relation between the new paradigm and the old cannot be seen simply as one of extension or refinement. Instead, the concepts involved in a paradigm shift may change in important ways, such as the concept "mass" that is independent of the object's velocity in Newtonian mechanics but dependent of the object's velocity in the theory of relativity. Proponents of different paradigms may therefore have difficulties communicating, because they use some concepts in different ways. Kuhn termed this relation between the paradigms separated by a revolution or paradigm shift "incommensurability," a term that comes from mathematics where it means "no common measure."

According to Kuhn, the phased development of science – paradigm, crisis, revolution, new paradigm, etc.–, presupposes that a paradigm has been established so that there is consensus within the scientific community on various fundamentals. A distinction can therefore be made between the pre-paradigmatic stages of science while it is still characterized by a plurality of competing schools of thought and its mature stages when a shared paradigm has been developed.

The term paradigm has been used in several different ways. Sometimes it is used to denote concrete exemplary problems and problem solutions, sometimes it is used to refer to classical texts from the history of a discipline, and sometimes it is used to denote the entire global set of commitments shared by the members of a given scientific community. It has therefore been criticized for its ambiguity, and in response to this criticism, Kuhn tried to disentangle the various uses by introducing the idea of a disciplinary matrix containing four different elements: (1) the symbolic generalizations that are used within a given discipline, that is, the scientific laws in their most fundamental forms (e.g., Newton's second law of motion, $F = ma$); (2) beliefs about which objects and phenomena exist in the world (e.g., that forces exist); (3) values by which the quality of research can be evaluated (such as accuracy or consistency); and (4) so-called exemplars which are the exemplary problems and problem solutions that scientists from a given discipline work on and recognize.

Paradigms in the form of exemplary problems and problem solutions play a special role in science education. Kuhn argued that textbooks do not describe the problems which a discipline addresses in the abstract; instead they exhibit concrete problem solutions and ask the students to solve additional problems that are closely related to those that have been displayed in the textbook. In this setting, the term paradigm denotes standard examples, similar to how the term is used within language teaching.

Cross-References

- ▶ Empiricism
- ▶ Epistemic Goals
- ▶ NOS, Measurement of
- ▶ Science Studies
- ▶ Sociology of Science

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Participation, Gender-Related

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Participation and achievement in the sciences have varied over time, and currently, there are substantial differences by country and within cultural groups. The United States and the United Kingdom have similar patterns of participation and underachievement for girls and women in the sciences. Many other industrialized countries have higher participation rates and achievement for girls and women compared to the United States and United Kingdom. Many developing nations have low participation rates due to access, societal and religious norms, and other factors. Across and within countries, cultural attitudes and expectations play a significant role in the participation of women and girls in science.

In the United States, adolescence typically corresponds to a decline in girls' interest, participation, and achievement in science. This is attributed partly to peer influences and a desire to be popular and well liked. Students start to identify science careers and scientists as isolated, hard, and masculine. As evidenced by research such as the Draw-a-Scientist Test, where students are asked to draw someone who is a scientist, it is clear that children and adolescents have clear expectations of who does science. This activity has repeatedly resulted in students drawing older white men in lab coats with unruly hair and glasses, reminiscent of Albert Einstein. The perception that scientists should look like that can be problematic for individuals who do not identify with this image, such as girls and underrepresented minorities.

Self-concept and identity are believed to play a substantial role in the differential participation rates in science. Science is often characterized as masculine, leading students with a more feminine gender identity to see a scientific career as incompatible with their conception of self. Additionally, research has shown that students who possess a scientific self-concept are more likely to be interested in pursuing a science major or career. Some of the challenges with the narrow perceptions of scientists and science careers stem from a lack of positive role models. This is a circular problem, as the lack of diversity in science perpetuates scientist stereotypes, thereby limiting students' interest in pursuing science when they cannot identify with scientists and do not develop a scientific self-concept.

Perceptions of science and scientists are not isolated to students; they are also present in teachers. These inherent beliefs about who is capable of doing science can unconsciously be passed on to students through teachers' classroom behaviors. If boys are encouraged to enter science fairs, participate in science outreach activities, or engage in scientific inquiry when girls are not, it can generate a cultivated lack of interest in girls and sense that they should not be doing science. Likewise, research has shown that teachers often expect boys to excel in math and science, making them more likely to call on boys for answers during class and less likely to call on girls. These messages send clear signals to girls about their abilities and social expectations about scientists, even if the messages are unintentional. Sexism, overt or otherwise, can be a barrier to girls' participation in science.

Mathematics achievement, self-efficacy beliefs, and course enrollment have also been related to science participation. Girls tend to take fewer math and science courses in junior high school and high school, which is disadvantageous to pursuing a science major or career. Taking more math and science courses predicts later academic success in STEM and is correlated to higher confidence and a higher likelihood of choosing a STEM major in college. Research has shown there is a difference in the confidence and self-efficacy beliefs of boys and girls, which has also been attributed to the lower participation by girls in science. Some of the differences seen in confidence levels can be attributed to perceived preparation, with girls and women feeling behind compared to boys and men. Additionally, when making peer comparisons, girls tend to underestimate their abilities, while boys overestimate their abilities even when they are equally prepared and qualified.

Cross-References

- ▶ Achievement Differences and Gender
- ▶ Careers and Gender
- ▶ Gender-Inclusive Practices

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Pedagogical Content Knowledge

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Keywords

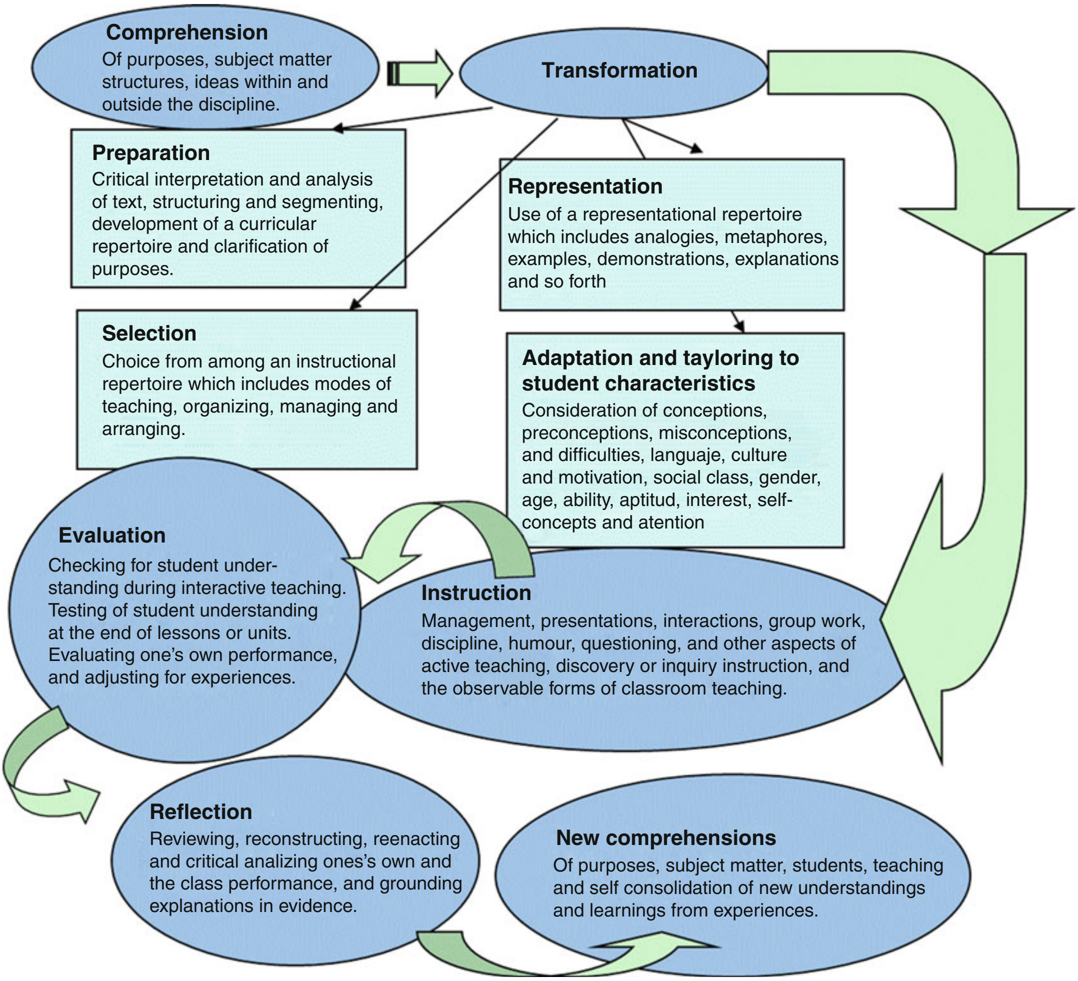
Content knowledge; Filters; Subject knowledge; Teacher beliefs; Teacher knowledge

At the October 2012 PCK Summit in Colorado Springs, USA, a group of international scholars met to share definitions, applications, and interpretations of the construct of pedagogical content knowledge (PCK). The following description was proposed by one of the discussion groups and adopted by consensus: PCK is "defined as a personal attribute of a teacher and is considered both a knowledge base and an action . . . [It is the] knowledge of, reasoning behind, planning for, and enactment of teaching a particular topic in a particular way for a particular reason to particular students for enhanced student outcomes" (Gess-Newsome and Carlson 2013). The four times that the word "particular" appears in this definition is a double-edged sword. On one hand, it means that PCK must be reconstructed specifically each time a given teacher, within set objectives, has to present a certain topic to a specific set of students with a distinctive background and learning characteristics. On the other hand, it represents a superb challenge, being that PCK is an academic construct that represents an intriguing idea, rooted in the belief that teaching requires much more than delivering content knowledge to students, involving designed purposes and the best ways to represent and evaluate that knowledge.

PCK has been a field within which much science education research has been conducted. The array of publications range from Gess-Newsome and Lederman's (1999) book that combined several visions of PCK, looking at ways of assessing and measuring the construct and its impact on science teacher education programs, to the Kind (2009) extended paper where an analysis of PCK models was conducted alongside an examination of methods of elucidating PCK in experienced and novice teachers.

The idea of PCK is enticing because it seems to be such a clever way of imagining what the specialist knowledge of teaching might involve. PCK is complex and usually so deeply a part of a teacher's intrinsic practice that it is tacit and, more often than not, largely inaccessible. The difficulties allied to making more use of PCK lie in its elusive nature. PCK conjures up an image of cutting-edge knowledge of practice, something special and important, something that could define expertise, something that could illustrate, in a meaningful way, why teaching needed to be better understood and more highly valued. PCK is the knowledge and beliefs that teachers develop, over time and through experience, about how to teach particular content in particular ways in order to enhance student understanding.

The term PCK was first coined by Lee Shulman three decades ago. Reflecting on his original lecture entitled "The Missing Paradigm in Research on Teaching" (presented at the University of Texas at Austin, summer 1983), he commented that "most [people] were shocked when I declared that the missing paradigm was the study of subject-matter content and its interaction with pedagogy" (Gess-Newsome and Lederman 1999, forward). In an elaboration of his original concept, Shulman (1987) proposed seven categories of a teacher's knowledge base: orientations, general pedagogical knowledge, content knowledge, curricular knowledge, knowledge of learners, contextual knowledge, and pedagogical content knowledge. We can see that this list includes pedagogical content knowledge as part of the knowledge base that a teacher should possess and enact while teaching.

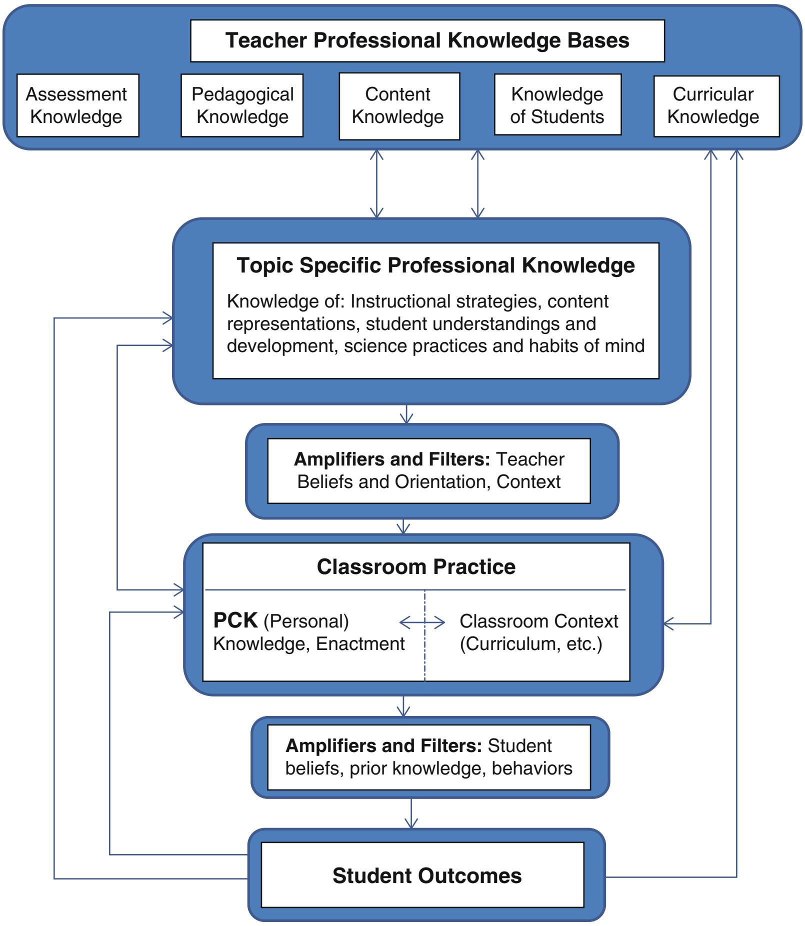


Pedagogical Content Knowledge, Fig. 1 A model of pedagogical reasoning and action (Diagram reproduced with permission from Salazar (2005), based on information first presented by Shulman (1987))

In the last part of his 1987 article, Shulman developed a "model for pedagogical reasoning and action," a diagram of which is presented in Fig. 1. This diagram shows the sequence of considerations made by teachers each time they go through an instructional activity on a specific topic; starting from comprehending the content, they transform it in intelligent representations, selecting them from their repertoire and adapting the representations to the actual student characteristics. The second stage of the process is a cycle in which the instruction is followed by its evaluation, a reflection of the class's performance and a new set of comprehensions in a spiral trajectory that overlays the preparatory stages for subsequent activities.

It has to be emphasized that beliefs and knowledge permeate all of the components of PCK. In the PCK Summit, Marissa Rollnick mentioned that she conceives that beliefs act as a filter that the teacher, unwittingly, places between the knowledge base and his/her action in the classroom or laboratory. Gess-Newsome and Carlson (2013) included the filtration idea in their most recent PCK model, illustrated in Fig. 2. Assessment, content knowledge, pedagogical knowledge, knowledge of students, and context knowledge compose the knowledge base of the teacher, but all that is filtered by the teacher's beliefs, orientation to, and context

Pedagogical Content Knowledge, Fig. 2 Situating PCK within teacher professional knowledge and influences on classroom practice and student outcomes (Reproduced here with permission)



of, the practice of teaching where classroom context also acts. The final purpose of teaching is to increase student learning outcomes, but that is mediated (or filtered) by a set of factors that enact in each one of the students in different ways, because of their individual motivations, behaviors, alternative conceptions, learning styles, and knowledge constructions.

In summary, ensuring that teachers have good content (subject matter) knowledge is only part of the story for a science teacher: possession of effective teaching skills, paying close attention to a teacher's "amplifiers and filters," is also needed. As a closing remark, we copy two questions that Sandra Abell (2008) posed to PCK researchers as future challenges: "What is the relation of PCK (in terms of quality and quantity) to teacher practice?" and "What is the relation of PCK to student learning?" (p. 1412).

Cross-References

- ▶ Pedagogical Knowledge
- ▶ Science Teachers' Professional Knowledge
- ▶ Teacher Contextual Knowledge
- ▶ Teacher Craft Knowledge

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Pedagogical Content Knowledge in Teacher Education

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Keywords

Science teacher education; Subject matter knowledge for teaching; Teacher knowledge; Teacher learning

Introduction

The term pedagogical content knowledge was introduced by Lee Shulman in his presidential address to the American Educational Research Association (Shulman 1986). Shulman argued that for a long time, research on teaching and teacher education had undeservedly ignored questions dealing with the content of the lessons taught. Shulman presented a strong case for pedagogical content knowledge (PCK) as a specific form of knowledge for teaching which refers to the transformation of subject matter knowledge in the context of facilitating student understanding. Fundamental in the definition of PCK is the notion that teachers' knowledge of strategies to teach a certain topic is related to, if not based on, their knowledge of how students learn that topic and their understanding that students' learning may vary according to the learning abilities of the student, the context, and so on. Shulman suggested that the more teaching strategies teachers have at their disposal within a certain subject domain, and the better they understand their students' learning processes in the same domain, the more effectively they can teach in that domain.

Teacher Education

In the past 20 years, a plethora of publications studying and integrating PCK into teacher education have been published in the research literature. Publications have addressed various subject areas, including English, mathematics, science, physical education, and social studies. In the domain of science education, various studies have been conducted into ways of structuring and organizing preservice science teacher education programs to promote the development of PCK (for overviews, see, for instance, Gess-Newsome and Lederman 1999; Abell 2007). However, the reported impact of such programs on the development of preservice science teachers' PCK is varied. The most successful programs address both preservice teachers' subject matter knowledge and their educational beliefs in the context of learning to teach certain topics. Such programs combine various elements, including the use of relevant research literature (i.e., on student learning of subject matter), the design of lesson series, opportunities to teach these lessons, and reflective activities – such as writing reports and sharing teaching experiences in collective meetings (see Van Driel and Berry 2010). Studies in this context concluded that the development of PCK is a complex process which is connected with deepening of subject matter knowledge and improved awareness of pedagogical issues. It would appear, however, that preservice teachers often experience difficulties merging subject matter courses and education courses that are not integrated by design. In the context of such nonintegrated programs, it has been demonstrated that knowledge development appears most strongly influenced by individual and contextual factors, resulting, among other outcomes, in the adoption by preservice teachers of "conventional" instructional strategies, stressing facts and procedures instead of student understanding.

Science Teachers

In studies on experienced science teachers, it was also found that PCK is quite sensitive to personal characteristics of teachers and their working contexts. Several studies have reported substantial differences between the PCK of experienced teachers around the same topic area, even when their subject matter knowledge is similar, and when they teach the same curriculum. These differences appear to stem from a range of factors including different orientations towards teaching science that teachers may hold; different purposes of teaching science, often related to local curricula; and other contextual factors. The development of PCK is perhaps then best viewed as a complex interplay between knowledge of subject matter, teaching and learning, and context and the way teachers combine and use this knowledge to express their expertise.

Conclusion

Concluding this brief review, PCK should be considered as dynamic, that is, for a certain topic, it develops over time, based on teachers' experiences teaching that topic more often. Specific interventions, in teacher education or professional development programs, can contribute to enhancing science teachers' PCK. In addition, PCK needs to be flexible, so that teachers are able to adapt their approaches to accommodate for differences between individual learners and specific classroom situations: An effective way to teach a certain science topic on Monday morning in a certain class may not work very well in a different class on Wednesday afternoon.

Notwithstanding the complexity of PCK, and its sensitivity to personal and contextual factors, it seems possible, and worthwhile, to capture and portray PCK in such a way that key notions of teaching and learning a specific science topic are made explicit. Also, discussing and sharing such key notions among science teachers may contribute to the establishment of a "collective" PCK, that is, a shared or common form of teachers' professional practical knowledge about teaching certain subject matter. At the same time, there should, of course, be room for individual teachers to adapt or complement this shared knowledge to their own situations.

Cross-References

- ▶ Curriculum in Teacher Education
- ▶ Teacher Professional Development
- ▶ Pedagogical Content Knowledge
- ▶ Pedagogical Knowledge

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Pedagogical Knowledge

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Keywords

Pedagogical content knowledge; Teacher knowledge; Teacher Learning

Pedagogical knowledge (PK) is a term used for knowledge of how to teach that is applicable across a range of teaching areas. The term general pedagogical knowledge (GPK) is sometimes used as a synonym so that a distinction can be made between knowledge of how to teach generally and knowledge of how to teach a particular subject area which is usually referred to as pedagogical content knowledge (PCK). Shulman (1987) described seven types of teacher knowledge: content knowledge, general pedagogical knowledge, curriculum knowledge, pedagogical content knowledge, knowledge of learners, knowledge of educational contexts, and knowledge of educational aims, purposes, and values. General pedagogical knowledge (GPK) is described as "those broad principals and strategies of classroom management and organisation that appear to transcend subject matter" (Shulman 1987, p. 8). Some writers have used each of the knowledge types described by Shulman separately in describing teachers' work, while others have used different amalgams of the types so that teachers' work can be seen more holistically. The relationship of GPK to other knowledge types is of interest.

Gess-Newsome (1999) suggests that a model of teacher knowledge in which teachers draw on separately developed knowledge types in a flexible manner, to suit particular teaching needs, is an Integrative Model. In contrast, a Transformative Model is one in which a new knowledge form is synthesized from other forms of knowledge into a different way of knowing, more powerful than the separate parts that go into its development. For example, PCK is commonly seen as a transformation of content knowledge or subject matter knowledge, pedagogical knowledge, and knowledge of context into a new knowledge that is of use during the complex act of teaching. Thus PK or GPK is part of, or a contributor to, knowledge for teaching particular subjects so that students understand them. Researchers have found that strongly developed GPK can support the development of PCK where other contributing knowledge types are still growing (Sanders et al. 1993). Similarly, underdeveloped GPK appears to slow the development of PCK particularly in beginning teachers (Mulholland and Wallace 2005).

Cross-References

- ▶ Classroom Organization
- ▶ Pedagogical Content Knowledge
- ▶ Science Teachers' Professional Knowledge

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Pedagogy of Teacher Education

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Keywords

Self-study

Background

Pedagogy of teacher education is a term that is used to describe the knowledge and practice of teaching and learning about teaching. It is a construct that emerged in the literature based on the notion that teachers of teachers require specialist knowledge and skills about teaching that are particular to the teaching of teaching. Following on from studies in the 1970s and early 1980s aimed at defining expertise in teaching, that which teacher educators need to know and be able to do to prepare the next generation of teachers started to attract serious attention from teacher educators themselves. As a consequence, teacher education programs came under scrutiny and questions about how best to prepare teachers created a need to better understand how learning about teaching was influenced by student teachers' experiences in their teacher education programs.

A Starting Point

Heaton and Lampert (1993) argued that a pedagogy of teacher education offered ways of challenging traditional teacher preparation programs and, if genuinely grasped by teacher educators, could create innovative opportunities through which the problems of practice could become pivotal in learning to teach. A strong example of how this focus on teaching and learning about teaching moved toward the center of teacher educators' efforts was captured in *Teachers Who Teach Teachers* (Russell and Korthagen 1995). Russell and Korthagen's collection illustrated how the hopes, expectations, and knowledge of teaching about teaching began to be more rigorously researched by teacher educators and marked a shift in who did the research that counts in teacher education (i.e., external researchers who observed teacher education or those involved in the work of teaching about teaching). Teacher educators started to break new ground through a focus on, and methodologies for, researching their own and their students' learning of practice that mirrored that of the teacher research movement in schools. As teacher educators began to question and coalesce around the value of researching their own teaching, self-study of teaching and teacher education practices (Hamilton et al. 1998) began to take hold and gain traction in the research community.

Self-Study and a Pedagogy of Teacher Education

The self-study movement was very attractive to teacher educators as it raised the profile, not only of their work but the knowledge and practice crucial to making that work more highly valued. As the literature in self-study grew throughout the 1990s and the first decade of the 2000s, the notion of a pedagogy of teacher education became more prominent; perhaps because it was one way of conceptualizing and articulating knowledge of teaching and learning about teaching in more meaningful ways for teacher educators. As a consequence, the concentration of research on the teaching of teaching, teacher education program structure, and organization came under scrutiny and was often perceived as defining teacher education, not always in positive ways. Hence, a pedagogy of teacher education offered ways of breaking free from the constraints derived from program structures.

Principles of Practice

Korthagen's concerns about the structure of teacher education and how it shaped the nature of learning led him to focus attention on the importance of a pedagogy of teacher education as described in the book *Linking practice and theory: The pedagogy of realistic teacher education* (Korthagen et al. 2001). In that book he proposed three central principles that shaped his notion of a pedagogy of teacher education; they were that the teacher educator should help the student teacher (1) to become aware of his or her own learning, (2) to find useful [learning] experiences, and (3) to reflect on those experiences in detail. The essence of Korthagen's approach to a pedagogy of teacher education then was for teacher educators to explicitly implement teaching of teaching strategies constructed through, and responsive to, his three principles. In so doing, a shared knowledge of practice could become a tangible outcome in student teachers' learning to teach and also help teacher educators build their knowledge of practice in constructive ways.

Refining a Pedagogy of Teacher Education

The notion of a pedagogy of teacher education placed the knowledge and practice of teaching and learning about teaching at the heart of teacher education in new ways and became more prominent in the literature throughout the later part of the first decade of the 2000s. What a pedagogy of teacher education is and how it might be better understood and developed was conceptualized in an explicit way through *Developing a Pedagogy of Teacher Education* (Loughran 2006) which highlighted the distinction between the *teaching* of teaching and the *learning* of teaching. In so doing, a pedagogy of teacher education was conceptualized around the specific aim of building deeper understandings of the knowledge and practice of teaching *and* learning about teaching.

From the teaching about teaching perspective, there are important aspects of being a teacher educator that are seen as influencing knowledge of practice. For example, making the shift from being a (science) teacher to being a (science) teacher educator has implications for how the role of teacher educator is constructed and performed. Underpinning this shift is the recognition that simply "doing teaching" is not sufficient for framing the work of being a teacher educator. Becoming a teacher educator is much more than a change in title or a change in the place in which teaching occurs. Being a teacher educator involves understanding pedagogy in ways that involve the explicit development of a shared language of teaching and learning, of approaching practice as being problematic, and of recognizing and responding to principles of practice such that a major effort is made to better align "thoughts and deeds" in teaching about teaching.

From a learning about teaching perspective, recognizing and responding to what it feels like to be a student teacher matters. The ways in which learners are encouraged to, and supported in, reflecting on their learning about teaching are crucial. One way of doing that through a pedagogy of teacher education is to adopt a student teacher as researcher stance, "students of teaching live a different reality in learning to teach than do their professors who observe their students' situations, and so, students of teaching are rightly the experts in relation to understanding *their* context, *their* position and the expectations *they* feel, face and create for themselves . . ." (Loughran 2006, p. 139). When teacher educators create conditions for learning and trust their students to capitalize on their learning about teaching experiences, that learning becomes more important, more meaningful, and more highly valued.

Science Teacher Education

Berry (2007), in her examination of what she described as tensions in teaching about Biology teaching, was an early leader in articulating a pedagogy of (science) teacher education. It could well be argued that her notion of tensions illustrated ways for others to frame their learning about the teaching of science teaching. In fact, in *Self-Studies of Science Teacher Education Practices* (Bullock and Russell 2012), a collection of studies based around a pedagogy of teacher education was articulated and portrayed within the specific context of the teaching of science teaching. The book highlighted a number of recurrent themes central to the issue of teaching and learning about science teaching, but one in particular was that of tensions, embodied in the tension between transmission and interpretation. This tension draws on common ground evident in archetypes of science teaching and teacher education that encouraged science teacher educators to look more deeply into their teaching and their students' learning. In attempting to engage student teachers in learning through inquiry, by attempting to create curious and puzzling pedagogical situations, and in supporting the notion of risk taking and experimentation in learning to teach, science teacher educators actively pursue a pedagogy of teacher education that makes their purposes and actions explicit, clear, and meaningful in their science teacher preparation programs. Their pedagogy of teacher education is strongly associated with the desire to dispel transmissive approaches to teaching and passive behaviors in learning. Bullock and Russell's book illustrates well how the use of pedagogical practices can help not only teacher educators but also student teachers, to develop their pedagogical reasoning and thus become better informed about the nature of science teaching and learning.

Overview

At its core, a pedagogy of teacher education considers teaching as much more than the delivery of information about how to teach. A pedagogy of teacher education places great value on the knowledge and practice of pedagogy as evident in the scholarship and expertise of expert teacher educators. The juxtaposition of similar underlying concerns about the nature of science teaching and teacher education makes the pedagogy of (science) teacher education a particularly powerful vehicle for supporting the development and articulation of (science) teaching *and* learning about teaching.

Cross-References

- ▶ Self-Study of Teacher Education Practices (S-STEP)
- ▶ Pedagogical Content Knowledge in Teacher Education
- ▶ Pedagogical Knowledge

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Physics Teacher Education

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Keywords

Learning to teach; Pedagogy; Physics; Teacher education

Physics teacher education shares similar concerns to programs for preparing teachers of other science disciplines through its fundamental focus on student-centered teaching. However, there are important differences between physics and the other science disciplines, and these strongly influence the pedagogy of physics teacher education (Tiberghien et al. 1997, 1998).

How Physics Differs from Other Sciences

Physics is regarded as the most fundamental science. It has a reputation as being abstruse, difficult, and highly mathematical. It differs from the other science disciplines in a range of ways. For example, although common in biology, teleological explanations are unacceptable in physics because of their anthropomorphic connotations. Physics has relatively few theories and their predictive power is strong; by contrast biology has many theories but their predictive capacity is often lacking. Logic and parsimony are highly valued in formulating physics explanations but play a less significant role in other sciences such as biology and chemistry which deal with more complex systems and behaviors.

What Preservice Teachers Typically Learn in Physics Courses

Typically, preservice teachers develop their physics knowledge in courses taught by university physics departments (or, frequently, engineering departments) where the treatment of physical laws is very mathematical, and lectures and laboratory work comprise the standard approach to teaching. The nature of physics explanations and other philosophical issues are rarely explicitly addressed.

There is considerable research to suggest preservice teachers' experiences as learners in such courses often profoundly influence their approach to teaching physics. That is, in learning physics, they also learn about a pedagogy of physics teaching whereby the teaching of a topic often begins with definitions of concepts and developing relevant physics equations which are confirmed by laboratory activities. Conceptual understanding is assumed to develop through solving quantitative problems. However, a large body of research has found this approach to teaching often fails to develop deep conceptual understanding of even otherwise successful learners. Consequently, preservice teachers often emerge from such courses with inadequate understandings of the subject they intend to teach and a view of teaching and learning physics which is at odds with that presented in physics teacher education courses (Mulhall and Gunstone 2012).

What Preservice Teachers Typically Learn in Physics Teacher Education Courses

Physics teacher education courses promote the importance of developing students' understanding of physics concepts using qualitative approaches. They challenge the traditional view, noted above, that a proficiency in problem solving guarantees adequacy in conceptual understanding. They explicitly consider the inherent difficulty of many physics concepts. Using a constructivist view of learning, preservice teachers are taught to begin their teaching of a topic by finding out what the physics learner already knows and believes and to develop understandings by providing experiences in which learners engage qualitatively with physics concepts *before* being introduced to mathematical representations. Ways of using laboratory work to promote effective learning are also considered, given research indicates that the forms of laboratory work typically used in schools and universities often fail to promote learning.

Promoting the importance of qualitative approaches that encourage students' intellectual engagement with physics concepts requires attending to assessment practices, as it is well recognized that learners focus on that which is going to be assessed. The traditional approach to assessment in physics promotes the capacity to solve standard textbook problems but does little to support the development of conceptual understanding. For this reason, physics teacher education addresses qualitative ways of assessing conceptual understanding in addition to the quantitative approaches that are familiar to preservice teachers through their prior experience as physics learners.

Approaches to Developing Preservice Teachers' Practice

Constructivism informs the approach taken to teaching physics preservice teachers to teach. As noted above, they tend to have preconceived views about teaching physics that were developed during their previous experiences of learning physics so they expect physics teacher education courses to merely teach them tips and tricks that can be employed in the classroom. Challenging and developing their views is often achieved through placing them in the role of learners of physics in which they discuss ideas about the physics of a situation presented to them in, for example, a demonstration, qualitative physics problem, or POE ("predict-observe-explain") activity. This typically reveals a range of understandings and misconceptions about the phenomenon under discussion. These discussions serve a number of purposes and help to reframe preservice teachers' thinking about teaching physics in ways that develop their practice. Firstly, they help advance the conceptual understanding of the preservice teachers and thereby model a teaching approach that they can use successfully with their own learners. Secondly, these discussions also facilitate preservice teachers' recognition of the importance of paying attention to developing qualitative as well as quantitative understandings in the physics classroom. In so doing, the preservice teachers develop rudimentary forms of pedagogical content knowledge, which may be further advanced using CoRes (Content Representations) and PaP-eRs (Pedagogical and Professional-experience Repertoires) in specific topics (Loughran et al. 2012).

Inevitably such discussions also involve epistemological and ontological issues (e.g., How we know what we know? What do we think exists?). Thinking about such questions, which are rarely addressed in physics courses, helps promote reflection by preservice teachers about their students' intended learning and the importance of teaching physics as "a way of knowing." Extending these discussions to include a consideration of the role of peer review and notions of uncertainty in physics knowledge claims is increasingly seen as being important in the education of physics teachers, given the current trend of curricula in various science disciplines to include the theme of science as human endeavor.

Cross-References

- ▶ Biology Teacher Education
- ▶ Chemistry Teacher Education
- ▶ Epistemology
- ▶ General Science Teacher Education
- ▶ Modeling Teaching
- ▶ Pedagogical Content Knowledge in Teacher Education
- ▶ Pedagogy of Teacher Education
- ▶ Secondary Science Teacher Education
- ▶ Science Teachers' Professional Knowledge

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Piagetian Theory

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Keywords

Child psychology; Developmental stages; Epistemology; Equilibration process; Piaget

Introduction

It is ironic that Jean Piaget is widely known as a child psychologist, yet he himself did not identify with this label. Rather, he used the term *genetic epistemology* to describe his work. In this context, *genetic* does not refer to genes but to the origin and development of knowledge. Usually, *epistemology* refers to the study of the nature, sources, scope, and validity of knowledge, and it is considered to be a branch of philosophy. Piaget, however, did not believe that epistemological issues fall under the sole jurisdiction of philosophy. Instead, Piaget argued that empirical methods can contribute to the solution of epistemological problems, particularly because knowledge itself is in constant flux and always remains incomplete. Thus, rather than an end in itself, the study of cognitive development in children was for Piaget only one means to address epistemological issues. This also explains why Piaget was not at all interested in determining the cognitive level of an individual child; rather, he was interested in what is common to all children at a specific level of thinking – what Piaget referred to as the *epistemic subject*.

The central questions that Piaget's genetic epistemology aims to address are concerned with the creativity and rigor of knowledge. Creativity manifests itself as novelty that emerges at every level, from the biological to the highest cognitive level of functioning. At the same time, human knowledge, particularly logical and mathematical knowledge, is rigorous and logically necessary ($2 + 2 = 4$ could not be otherwise and must universally hold to be true for all rational persons, provided we are operating in a base 10 numerical system). Piaget's answer to these questions is a particular brand of constructivism that has a biological foundation. Ultimately, his answer is grounded in the nature of life: "the very nature of life is constantly to overtake itself, and if we seek the explanation of rational organization within the living organization *including its overtakings*, we are attempting to interpret knowledge in terms of its own construction, which is no longer an absurd method since knowledge is *essentially construction*" (Piaget 1971, p. 362, emphasis in original).

In this essay, we first describe the key concepts of self-organization, assimilation, accommodation, scheme, operative and figurative aspects of intelligence, equilibration, and constructivism. Then we provide a brief review of the main characteristics of Piaget's four developmental stages. Finally, we examine the roles of consciousness, semiotic function, affectivity, and social interactions in Piaget's theory. Because of the scope of Piaget's work, our essay necessarily is selective. We refer the reader to the monographs by Chapman (1988) and Smith (1993) and the edited volume by Müller et al. (2009) for a more detailed coverage of the topics presented here.

Self-Organization

It is generally accepted that psychological development has a biological basis. The question is how the relation between biology and psychological development should be conceptualized. Currently, a popular approach is to reduce development to the unfolding of hereditary programs or to the maturation of particular areas of the brain. Piaget considered such reductionist approaches inadequate because they fail to capture essential characteristics of psychological functioning: the consciousness of meaning and the irreducibility of implication to causality (see below).

Piaget used the concept of self-organization to characterize the relation between biology and psychological development (see Piaget 1971). At the biological level, *self-organization* is the process by which a system perpetually reconstitutes its processes (e.g., metabolic cycles) and elements (e.g., cells) in order to preserve its continuous functioning. Living systems are self-organizing systems; in exchange processes with their environment, they spontaneously reproduce their organization. Machines, by contrast, are not self-organizing systems; their functioning does not result in their reconstitution, and their reproduction is controlled by an external agent.

In its evolution, the continuously self-organizing process leads to the emergence of higher-order self-regulatory processes, which, on the level of cognitive functioning, reflects the basic mechanisms (i.e., the logic or reason) of self-organization and, at the same time, constitute the most complex instruments for regulating the exchange with the environment (Piaget 1971). Cognitive functioning reflects reason in a double sense: it is the product of reason that is intrinsic to nature (i.e., in the logic of self-organization) and through cognitive functioning reason in nature becomes conscious of itself.

Piaget thus argues that cognitive processes are the outcome of and extend the processes of organic self-organization by using and adapting to new circumstances the different systems of organic self-regulation that can be found on the genetic, morphogenetic, physiological, and nervous levels. In support of this claim, Piaget describes many functional and structural analogies between cognitive and organic functioning. Central among these analogies is the triad of assimilation, accommodation, and scheme.

Assimilation, Accommodation, and Scheme

The complementary functions of assimilation and accommodation describe the general characteristics of the exchange between organism and environment. Assimilation is the aspect of an organism's activity wherein elements of the environment are integrated into the organism's preexisting organizational structures (i.e., the relations between elements). Accommodation, on the other hand, provides the material for the structuring activity of assimilation. Accommodation is the aspect of the activity wherein an organism's existing schemes are differentiated and modified in response to the environment. For example, a preexisting metabolic cycle assimilates particular nutrients by breaking them down into the elements that contribute to the continued functioning of the living system. The assimilatory cycle needs to be modified when the organism encounters a new nutrient (accommodation) (Piaget 1963). Assimilation and accommodation maintain the equilibrium between an organism and its environment.

Assimilation and accommodation at the psychological level extend the physiological interactions between the organism and the environment because their functioning no longer depends on the incorporation of material elements but now incorporates informational content. At the psychological level, schemes are structures composed of affect, sensation, motor movement, and perception. Assimilation refers to the incorporation of new information into already existing schemes, a process giving meaning to the content (Piaget 1963, 1985). For example, when a baby grasps a rattle, the rattle is assimilated to his or her grasping scheme and thereby attains the functional meaning of being "graspable." Assimilation always uses the existing psychological scheme; its functioning carries the history of the subject's interaction with the world into each particular act. For example, an infant who has differentiated various ways of interacting with the rattle will have different action potentialities available compared to an infant who has not.

Accommodation refers to the modification of existing schemes to account for particular features of the object or situation. Because schemes are structures with varying degrees of generality, applying them to particular situations always requires an adjustment or accommodation. Accommodation thus particularizes the general schemes, supplies them with specific content, and modifies them in doing so (e.g., the preexisting grasping scheme needs to be modified, becoming more specific to take into account the particular spatial position of the rattle).

Assimilation, accommodation, and scheme are inseparable. Assimilation is always a structuring activity because it involves integrating content into existing schemes; thus, structures do not exist independently of structuring activity: "Assimilation is hence the very functioning of the system of which organization is the structural aspect" (Piaget 1963, p. 410). At the same time, the incorporation of new elements leads to the modification of the scheme and thus to accommodation. Accommodation brings about adaptation to the environment, but this adaptation is always a function of the structuring activity of assimilation.

Operative and Figurative Aspects of Intelligence

Closely related to the concepts of assimilation and accommodation are Piaget's notions of *figurative* and *operative* aspects of intelligence. The figurative aspect of intelligence includes the functions of perception, imitation, imagery, and (in part) language that are supplied by the accommodatory aspect of activity. The figurative aspect provides signifiers, which, in turn, provide the data on which the structuring activity of assimilation acts. For example, an infant may perceive a rattle, and, assimilating it to an action scheme, she recognizes rattle as something that can be shaken (i.e., the sight of the rattle serves as a signifier of what can be done with it).

In contrast, the operative aspect of intelligence, common to both sensorimotor actions and higher-order cognitive functions, refers to the transforming and form-giving, or structuring, aspect of knowledge. The operative aspect of intelligence transforms subject–object relation by inserting the data provided by the figurative functions into increasingly complex structures. In other words, the operative activity of the human mind results in the construction of more and more complex relations (spatial, causal, logical, etc.) between person and world, and the figurative aspect is subordinated to the operative aspect. The operative aspect of intelligence, then, is central to understanding the kinds of qualitative changes that occur in Piaget's account of cognitive development.

Equilibration

At each point in development, children are in a state of equilibrium with the environment, characterized by a particular balance of assimilation and accommodation. Development is a process that leads to increasingly more stable (complete and consistent) forms of equilibrium. Piaget termed this process *equilibration* (see Piaget 1985). The theory of equilibration takes central place in Piaget's later work (see Müller et al. 2009), in which he focused in more detail on the specific processes involved in equilibration. Although Piaget identified several processes as playing an important role in the equilibration processes, such as dialectics, contradiction, affirmation, and negation, the generation of possibilities, and the process of becoming aware, his theory of equilibration remains unfinished. Here we focus on the role of reflecting abstraction in equilibration, as reflecting abstraction is central to the construction of more powerful knowledge structures (Piaget 1971, 1985).

Reflecting abstraction is an elaborative process by which children discover the structural aspects of their cognitive activity. For instance, putting marbles, one after the other, in a receptacle is an action with several structural aspects, one of which is based on the creation of a serial order and another on the creation of a set with a growing number of elements. By becoming aware of the relations between and coordination of their actions, children abstract structure (the coordinatory or operative aspect of actions) from content and, in turn, project this structure to a higher cognitive level.

The mechanism of reflecting abstraction then ensures that development has an intrinsic logic and proceeds by way of successively conceptualizing the structures or forms of knowledge underlying previous knowing levels. Thus, the forms of stage n become the contents of stage $n + 1$. With each new and higher stage, the forms become increasingly abstract.

Constructivism

Piaget described his epistemic position as constructivism, and he saw this position as an alternative to empiricism and nativism. According to Piaget, the central ideas of empiricism are that the function of cognitive processes is to copy reality as closely as possible and that the mind is largely passive in this process. Piaget argued that these empiricist assumptions are conceptually flawed and are not consistent with empirical findings (see Piaget 1972). The idea that knowledge consists of a copy of reality is flawed because there would be no way to evaluate the accuracy of such copies as they cannot be directly compared to reality itself. In contrast to empiricism, nativism does not argue that knowledge comes from the outside but is innately prepared and lies dormant to be triggered by environmental stimulation. Piaget argued that nativism was contradicted by empirical findings that showed knowledge develops gradually and goes through a number of stages (see below).

As an alternative these interpretations of knowledge, Piaget (1970, p. 104) proposed that “in order to know objects, the subject must act upon them, and therefore transform them.” Piaget’s constructivist view implies that knowledge does not preexist in the world to be imposed on the children, nor is it already innately preprepared in the child. Knowledge develops through the subject’s interactions with the world; it is in the course of these interactions that the child comes to better understand the world by coordinating her own actions (Piaget 1954).

In contrast to empiricism and nativism, Piaget conceives of the subject as always active, interacting with the world. Without an active subject, there would be no novelty. Furthermore, the activity of the subject is always bound to a structure. For this reason, reality cannot be copied but only assimilated to the subject’s particular structural framework.

Developmental Stages

In standard psychology textbooks, Piaget is typically portrayed as a stage theorist who claimed that stages are general structures that define a child’s behavior in each area of cognitive functioning and that age is a criterion for stage. Consequently, it is argued that Piaget’s theory is flawed because empirical evidence shows that at any point in development, children’s behavior is heterogeneous and not homogeneous (e.g., they may reason at a preoperational level in one conservation task and at a concrete operational level in another) and that particular stages emerge earlier than Piaget would predict.

This portrayal of Piaget’s stage theory is utterly incorrect (Chapman 1988; Smith 1993). Piaget did not claim that stages are characterized by homogeneity, and, in fact, Piaget often made the opposite point that variability should be expected (Chapman 1988). Furthermore, variability in children’s performance on structurally similar tasks is entirely consistent with the basis of Piaget’s grounding assumption that thought originates in action. Based on this assumption, cognitive structures should, at first, be context- and content-specific. That is, cognitive structures cannot be separated from their content, and although structures involving different content (e.g., number and volume) may be of the same logical form, they develop independently in a functional sense through the child’s activity with these different areas of content.

Some of the extensive previous learning research in science education that is derived from Piaget’s views has these same fundamental flaws of assumptions of stages being characterized by homogeneity. This is particularly the case for at least some of those studies that have generated data from simple paper and pencil tests that claim to locate students at some constant point in a sequence of stages of development.

Stages are also not defined in terms of age. Rather, they are defined in terms of the performance on particular tasks that Piaget analyzed in terms of the operations and structure they require. He acknowledged that the age of acquisition of operations is highly variable and influenced by the amount of cognitive stimulation. Furthermore, central to Piaget was not the age at which the stages emerge but the mechanisms involved in stage transitions. Each stage is a temporary equilibrium in the process of equilibration. Because the stages build on each other, they constitute an invariant sequence. We next briefly describe the main characteristics of each stage (see Chapman 1988; Müller et al. 2009).

Sensorimotor Stage. Piaget (1963) termed the developmental period during approximately the first 18 months of life sensorimotor intelligence. It plays a key role in bridging the gulf between the biological level of functioning and rational thought. Sensorimotor intelligence is a practical, embodied intelligence on the basis of which infants interact with the world through perception–action cycles. At the sensorimotor stage, meaning is originally embedded in unreflective activities; objects have a functional, practical meaning, they are things at hand, utensils for practical use or manipulation. Infants employ action schemes like sucking, pushing, hitting, and grasping to explore and manipulate the world. At the outset, the newborn has no self-consciousness and no clear awareness of what effects she herself produces through actions on the world and what effects occur independently of her actions. By coordinating her actions and applying them in the social domain (imitation), the infant gradually learns to distinguish between self, other persons, and world. Piaget traced the process of differentiation and coordination of action schemes through several sensorimotor substages. For example, toward the end of the first year of life, infants construct hierarchical relations between actions by subordinating one action as a means (e.g., removing an obstacle) to another action as an end (e.g., grasping the rattle). The coordination and differentiation between actions results in the construction of increasingly complex relations between objects as reflected in the development of such basic categories as space, time, causality, and object (Piaget 1954). For example, in order to remove a cushion that is placed in front of an object, the child must realize for herself that the cushion, in fact, is placed in front of the object (space), that she must remove it before grasping the object (temporal series), that the object behind the cushion still exists (object-permanence), and that in order to remove the cushion, she must grasp it (spatialized and objectified causality).

The sensorimotor period ends with the emergence of symbol representations, which allow infants to transcend the immediate here-and-now. At the completion of the sensorimotor stage, for the infant, his own action is no longer the whole of reality and instead now becomes "one object among others in a space containing them all; and actions are related together through being coordinated by a subject who begins to be aware of himself as the source of actions" (Piaget 1972, pp. 21–22).

Preoperational Stage. The emergence of the symbolic or, as Piaget also termed it, semiotic function marks the onset of the preoperational stage, which extends from about 2 to about 7 years. The semiotic function underlies children's abilities to engage in a number of different activities, such as deferred imitation (i.e., imitation in the absence of the model), pretend play, drawing, psychological functions based on mental images (e.g., recall memory), and language. These activities are practiced and refined during the first substage of this stage, the level of preconceptual thought (approximately 2–4 years of age). At the same time, preoperational thought is characterized by profound cognitive limitations. For example, although preconceptual thought is no longer tied to particular objects or events (the here-and-now), it fails to distinguish between individual members of a concept and the generality of a concept. To illustrate, when Piaget's daughter Jacqueline was 31 months old, she cried upon seeing a slug, "There it is!" When she saw another slug a few yards further she said, "There's the slug again." Concepts thus remain midway between the generality of the concept and the individuality of elements composing it. On the one hand, there is no concept of a general class; on the other hand, particular objects have less individuality and easily lose their identity.

At the second substage of preoperational thought – termed *intuitive thought* – symbolic representational schemes become increasingly coordinated, and children become capable of relating two such schemes to each other by means of unidirectional logical relation. For example, in comparing the liquid in two differently shaped containers, children may use height in order to infer the amount of liquid, but ignore the width of the container. Intuitive thought thus remains centered on one dimension (e.g., height) and fails to establish bidirectional relations between dimensions.

Concrete Operational Stage. During the concrete operational stage, which emerges around 6–7 years, operations (i.e., internalized actions such as putting like objects together, putting objects in one-to-one correspondence) become coordinated and integrated into logical systems. As a result, children no longer center on one aspect of a situation, and they can mentally reverse transformations that have occurred in reality. The coordination of operations into systems also leads to the emergence of logical necessity.

Piaget devised a variety of conservation tasks to assess concrete operational thought. Conservation refers to the understanding that a whole exists as a *quantitative* invariant and therefore remains intact despite the rearrangement of its parts. For example, the number of objects in a set does not change by rearranging them (e.g., spreading them out). To understand that the quantity has not changed, children need to coordinate transformations in two dimensions (density of objects, length of row of objects). An operative understanding of conservation is logical in nature; it is not given by empirical observation of transformations.

Another concept that children understand at the concrete operational level is class inclusion. A typical class inclusion task requires children to compare the number of objects in the including or superordinate class with the number of objects in the most numerous of two of its subclasses. For example, given 12 daisies and 4 roses, children are asked, “Are there more daisies or more flowers?” A correct answer requires that children conserve the including class (B) while making the quantitative comparison between it and the included class (A). Although this may sound simple enough, such a comparison actually involves a multistep process in which children must not only be able to construct the including class, but also be able to reverse this operation by properly decomposing it. The first step involves being able to combine two subclasses to form a superordinate class, or A (daisies) + A’ (roses) = B (flowers). The second step involves performing the inverse (negative) operation associated with this combination of subclasses. This entails subtracting each subclass from the superordinate class such that A = B − A’ and A’ = B − A. The inverse operation, thus, implies that children construct each subclass through negation under the including class. Piaget termed this type of negation *partial* because it is applied to a part of a larger whole. Through partial negation children realize that the subclass A is an autonomous whole, which enables them to recognize that there are some B’s that are not A’s (e.g., there are some flowers that are not daisies) and that, therefore, there are more B’s than A’s.

Formal Operational Stage. The last stage of cognitive development described by Piaget emerges during adolescence. Piaget and his collaborator Bärbel Inhelder studied formal operations by presenting children and adolescents with concrete material (e.g., different weights, strings of different length) to be manipulated in order to discover scientific laws or the cause of a result from several possible factors (e.g., which factor – weight, length of string, height of dropping point, force of push – determines the frequency of the pendulum’s oscillation). These studies revealed that children approached scientific problems in a qualitatively different way than adolescents. Although children were capable of classifying and cross-classifying the independent variables, of properly ordering magnitudes of the independent variable along one dimension, and of putting these seriations into correspondence with their effects on the dependent variable, they failed to separate the involved variables by varying only one variable and holding all others constant. As a result, these children did not supply adequate proof for their statements. By contrast, from the outset, adolescents formulated hypotheses and derived conclusions from these hypotheses. They then proceeded to test these hypotheses by systematically controlling all variables except the one under investigation. Thanks to their systematic experimental approach, adolescents excluded hypotheses that were contradicted by observations and converged on the hypothesis that was actually true.

For Piaget, the difference between children's and adolescents' approaches to these problems suggested the reversal of the direction between reality and possibility: whereas in the concrete operational stage, possibility remains an extension of reality; in the formal operational stage, reality is subordinated to possibility. Adolescents are capable of thinking hypothetico-deductively by drawing necessary conclusions from truths that are considered merely possible.

Consciousness

The notions of assimilation, meaning, and consciousness are closely interrelated in Piaget's theory. At the psychological level, the structuring activity of assimilation comprises a need and is directed toward specific goals. It refers to particular elements or objects toward which human activity is directed and confers meaning on these elements. Assimilation thus captures the intentional nature of human consciousness that has been highlighted by continental European philosophers (Brentano, Husserl).

Consciousness is a system of meanings that are related to each other by implication. For example, the action of pulling a blanket upon which a rattle is placed in order to grasp the rattle shows that the infant understands that the spatial relation "placed upon" implies that the rattle is drawn along, especially if the infant does not pull on the blanket when the rattle is placed next to it. Logical necessity ("if $2 + 4 = 6$, then $6 - 2$ must be 4") and moral obligation ("I ought to") present other, more advanced cases of meaning implication. Meaning implications cannot be reduced to cause-effect relations (the truth of $2 + 4 = 6$ is not the cause of the truth of $4 - 2 = 2$ in the same way that hitting the patella is the cause of the knee jerk reflex).

Piaget's way of conceptualizing consciousness has two important consequences. First, the notion of causality does not apply to states of consciousness, not even at the level of sensorimotor intelligence, because causality is based on an external (independent) relation between cause and effect. Accordingly, neurophysiological approaches to sensorimotor intelligence remain incomplete because they fail to capture the intrinsic connection and the meaning-conferring, implicatory function of the structuring activity of assimilation. Second, it is easier to see how logical necessity can develop out of implications than how it can possibly emerge out of cause–effect (e.g., stimulus–response) relations.

How did Piaget conceive of the relation between consciousness and physiological processes? Piaget proposed that every psychological phenomenon has a physiological concomitant and that there is no causal connection between psychological and physiological phenomena (psycho-physiological parallelism). States of consciousness cannot provide a causal explanation of physiological processes and vice versa. Rather, Piaget thought that the structures of consciousness and physiological processes are isomorphic to each other, which amounts to an isomorphism between a system of implication and a causal system. At the same time, consciousness is not just an epiphenomenon because it adds value and understanding to organic and physiological processes.

Semiotic Function

Piaget held that consciousness is always based on signs or better signifiers. Signifiers are items that convey meaning. At the sensorimotor level, signifiers are not yet differentiated from their referent (signifieds). Signifiers at this level are termed *indications*. An indication is an "objective aspect of external reality" (Piaget 1963, p. 193), "a perceptible fact which announces the presence of an object or the imminence of an event (the door which opens and announces a person)" (Piaget 1963, pp. 191–192). Signifiers at this level are sensorimotor schemes that confer meaning on the elements interacted with.

At the end of the sensorimotor stage, the coordination and differentiation of schemes culminates in the emergence of signifiers that are differentiated from their signifieds. Piaget termed a system of such signifiers the *semiotic function*.

The semiotic function subsumes both symbols and signs. Piaget defined symbols such as mental images as signifiers that resemble the things signified, and signs, such as words, as arbitrary and conventional signifiers. The semiotic function makes it possible for children to form mental representations and to think about absent objects as well as past, future, and even fictitious events. It also increases the speed of processing because it makes it possible to imagine at the same time the successive phases of an action. Finally, it opens up the possibility of reflecting on and understanding the reasons why some actions are successful and others not (Piaget 1954).

During the preoperational period, children use symbols, among others, in symbolic play (e.g., a toy cup stands for a real cup), deferred imitation (e.g., imitating an action of an absent model), and drawing. Piaget believed that particularly young children need to rely on the use of individualized and personal systems of symbols. This is because personal symbols make fewer processing demands than language which is based on collective and arbitrary signs. Piaget recognized that language is essential to socialization, which, in turn, modifies action and behavior. Verbal exchange between individuals allows children to share ideas, and the resulting "collective concepts" reinforce individual thinking (Piaget 1995). Being more mobile than symbols, language also makes a unique contribution to the mobility of thought.

At the same time, neither language nor symbols are the source of the forms of thought found at the concrete and formal operational stages. According to Piaget, these forms of thought are grounded in the practical coordination of actions (e.g., grouping objects, seriating objects) at the sensorimotor stage. The semiotic function, and particularly language, is necessary for the interiorization of actions (i.e., without the semiotic function, operations would have to be executed as successive actions and could not be condensed into a simultaneous whole), but it is not sufficient to explain logical thought. In sum, Piaget considered the semiotic function only a tool used by and dependent on the operative aspect of intelligence.

Affectivity

Piaget believed that all behaviors involve an affective aspect and a cognitive aspect. The affective aspect is responsible for motivating the organism's interaction with the environment by assigning a value or goal to the behavior. However, achieving a particular end can involve a number of different paths. It is the cognitive aspect of behavior that structures such paths and thus the relation between the individual and the environment. In other words, affect provides the values and ends for actions, whereas cognitive functions are the means for achieving the ends.

To illustrate that any intelligent act contains both affective and cognitive contributions, take the following sensorimotor action: a child reaches for a toy by pulling on the blanket under the toy. This act has an affective component. In fact, two types of affectivity are involved in this act: synchronic affectivity (in the moment) and diachronic affectivity (over time). First, the child evaluates his current actions with feelings of success and failure (synchronic affectivity), and second, the child's evaluations of the situation involve a system of values that he has developed over time, engaging his interest in obtaining the toy (diachronic affectivity). These affective components regulate the cognitive component of the act that facilitated obtaining the object by pulling on the blanket. Thus, affect provides direction for intelligence, first by regulating interest and effort and second by assigning value to solutions sought. As such, for Piaget, affect and intelligence are inseparable, and Piaget often underscored the role of affectivity in intellectual growth.

Social Interaction

Piaget is often accused of failing to address the role of social interaction in development. This, however, is not the case (see Piaget 1995). Piaget was by no means oblivious to the role of the social in development, as attested by, for example, his statement that "human intelligence is subject to the action of social life at all levels of development from the first to the last day of life"

(Piaget 1995, p. 278). In his work Piaget struggled with the fundamental epistemological question: "Is it the individual as such or is it the social group that constitutes the motor or, if you prefer, the 'context' of intellectual evolution?" (Piaget 1995, p. 215). Piaget contrasts his own solution to this question with theoretical positions which suggest that rationality is derived either from the individual or the collective. By reducing the social to the aggregation of ready-made individual consciousnesses, individualism provides an atomistic explanation of the social and rationality. Collectivism, on the other hand, considers the social as a whole that cannot be derived from an additive composition of individuals. Rather, the collective whole is characterized by emergent novel properties and structures, and it modifies its members (i.e., individual persons, see Piaget 1995).

Piaget criticized both individualism and collectivism and proposed an interactive relational position as an alternative explanation of the role of social interaction in intellectual development. According to the interactive relational position, "there are neither individuals as such nor society as such. There are just interindividual relations" (Piaget 1995, p. 210). These relations between individuals are primary and "constantly modify individual consciousnesses themselves" (Piaget 1995, p. 136). The interactive relational point of view leads to a more fine-grained analysis of specific social relationships and their implications for development. Piaget describes two extreme types of social interaction: constraint and cooperation. Constraint involves the imposition of authority and group traditions on the individual; constraint does not promote cognitive and moral development. In cooperative interactions, relations are based on reciprocity and equality; cooperation promotes cognitive and moral development.

The upshot of the interactive relational view is that because the individuals must coordinate their actions vis-a-vis the world, "[i]ndividual operations and cooperations form one inseparable whole in such a way that the laws of the general coordination actions are, in their functional nucleus, common to inter- and intraindividual actions and operations" (Piaget 1971, p. 98). Individual operations and cooperations are subject to the same kind of combinations and transformations as actions and operations, thus the question of whether rationality is essentially social or individual becomes mute: "To wonder whether it is intrapersonal operations that engender interpersonal co-operations or vice versa is analogous to wondering what came first, the chicken or the egg . . . The internal operations of the individual and the interpersonal coordination of points of view constitute a single and the same reality, at once intellectual and social" (Piaget 1995, pp. 294, 307).

Conclusion

Piaget's theory is an astounding one in terms of both scope and depth. Piaget's theory addresses several fundamental epistemological questions such as the relations between biology and cognition, cognition and affect, the social and the individual, and nature and nurture. Piaget presents a systematic theory of the process of signification, the structure of consciousness, the role of action, and the experience in development. In these respects, Piaget's theory is still unparalleled.

Cross-References

- ▶ Constructivism
- ▶ Developmental Perspectives on Learning
- ▶ Epistemology

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Planetaria

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A planetarium (or planetaria in the plural form) is a form of purpose-built auditorium for displaying a presentation about the night sky and astronomy. The term was formerly used for devices that demonstrated the movements of the planets and Moon and, in pre-Copernican times, the Sun. Today, these devices would be referred to as orreries, after the Earl of Orrery who had one built for him in the eighteenth century. Modern planetaria date from the development of projectors, whereby the stars and planets are projected on to the inside of a domed roof. Developments throughout the twentieth century resulted in progressively sophisticated devices, most of which were projectors situated in the center of the auditorium, displaying stars and planets on the domed roof. By the 1980s, computerized projectors were being developed, and the current generation of digital projectors (including 3D) is able to handle not only astronomy visualizations as seen from Earth but also other contents such as flybys to other stars and the cosmology of black holes, as well as phenomena at the micro- and nanoscales. According to the World Planetaria database (www.aplf-planetariums.org), there are over 2,200 planetaria in use worldwide, of which 138 have sizable domes of 20 m or more. In 2012 it was estimated that nearly 115,000 people visit planetaria annually worldwide.

Learning in Planetaria

There is a long history of learning in planetaria, as they were developed for both educational and entertainment purposes. The main advantage of the planetarium is its dome, which represents the night sky in a three-dimensional manner together with an omnidirectional perspective, neither of which is possible to visualize on two-dimensional textbooks, chalk boards, or screens. Sky phenomena can be observed either in real time or, more commonly, by compressing time such that cycles are evident as being periodic (e.g., the phases of the Moon). Further advantages include the absence of light pollution and the addition of various audiovisual effects which enhance the realism and enjoyment of the show. Planetarium software is also available for computers as well as applications for mobile devices so that they can be pointed at the sky to identify visible objects.

The educational value of planetaria, which became very popular during the 1960s space race, has long been espoused, but there is relatively little research which shows their value. Smith (1974) found that although the majority of early research studies into the use of planetaria were of a descriptive nature and were not rigorous, it was useful for the development of the field due to its novelty. Later studies of an experimental, comparative nature had conflicting results, with some finding that planetaria enhanced learning and others refuting this. Other research was more focused on the curriculum, assisting schools to develop their earth science and astronomy curricula more effectively. Nearly 20 years later Riordan (1991) suggested that there was still no consensus that the educational use of planetaria was effective. However, a recent paper by Brazell and Espinoza (2009) describes a meta-analysis of 19 experimental, comparative studies carried out between 1966 and 2007 which provided sufficient statistics to calculate effect sizes. Their conclusion is that "the planetarium has been an effective astronomical teaching tool," which is good news for planetarium educators. An area which appears not to have been studied to any great extent is the effect of planetaria on people's attitudes towards science or astronomy. This is important, as people's affective domain is thought to be influenced by visits to other informal learning sites such as aquaria, zoos, and science centers.

In summary, planetaria have had a substantial history over the past century as entertainment and educational institutions that can effectively communicate science content about astronomy. As the technological devices they have access to become more sophisticated, their appeal is likely to become greater, allowing them to branch out into areas of scientific phenomena which can be visualized by such digital media.

Cross-References

- ▶ Aquaria
- ▶ Botanic Gardens
- ▶ Zoological Gardens

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Pluralism

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Two distinct types of pluralism exist in science education: methodological and philosophical. Methodological pluralism involves the premise that multiple methods of scientific research exist due to the fact that choices must be made depending on the nature of the research and the phenomena being studied. In this belief, there is no one method for all of science; therefore, a plurality of methodologies can exist. The different fields of study under the science umbrella allow for easier understanding of the existence of multiple methods for studying science. Philosophical pluralism, however, takes the idea of plurality to an abstract level in which humans' understanding of reality and truth creates multiple explanations of the phenomena of life. These explanations are influenced by cultural and historical context. In philosophical pluralism, subjectivity can never be fully removed; therefore, multiple truths, realities, and ideas coexist. Early pluralism debates were focused on the unity of science thesis, which included uniting all the sciences under one label to describe a general *science*. Pluralists view science as having distinct separations with multiple methodologies, investigations, and theories. Current pluralism discussions involve debates within particular sciences to debates about metascience concepts to discussion about how philosophy, history, and sociological accounts of science relate to one another. In the current educational climate, there is an appreciation and need for interdisciplinary approaches in science. When using the term *pluralism*, the distinction must be made between plurality in science and pluralism about the sciences. Plurality is a "feature of the present state of inquiry in a number of areas of scientific research," whereas pluralism is "a view about the state of affairs" (Kellert et al. 2006, p. ix). Understanding must also be established between monism and pluralism. Monism is the aim of science to discover one single explanation for the natural world and all principles and methods of inquiry can relate back to that one single explanation. Pluralism holds the belief that there is no one right explanation to fully explain the natural world.

Not all pluralists fit into the same category. The plurality spectrum ranges from modest to radical pluralists. Modest pluralists "tolerate a plurality of theories because it is difficult to predict which research program (or preliminary theory) will lead to a theory that provides a complete account of the phenomena" (Kellert et al. 2006, p. xii). Radical pluralists, more specifically constructivists, believe in an indefinite number of theories, which are only limited by human resourcefulness (Kellert et al. 2006, p. xiii). An additional division within pluralism is the battling ideas of competitive and compatible pluralism. In competitive pluralism, scientists test hypotheses in order to find the one correct theory. Competitive pluralists acknowledge the existence of multiple hypotheses, yet in this view, there is one theory that will represent the best answer and all other theories will be considered erroneous. In compatible pluralism, the scientific theories can coexist, meaning that multiple explanations could exist for one phenomenon. Compatible pluralists understand that hypotheses are not mutually exclusive.

Many opponents of pluralism wonder, if we are explaining *one* world, why are there multiple models, theories, and hypotheses? Some scientists may view the existence of multiple hypotheses as a sign of error. "The diversity of views found in contemporary science is not an embarrassment or sign of failure, but rather the product of scientists doing what they must do to produce effective science" (Mitchell 2002, p. 55). Science by nature is experimental. The idea of pluralism represents multiple ways in which scientists conduct, learn, teach, and understand science.

Scientific pluralism can be seen in curriculum debates, teaching methodologies, and teacher beliefs about the subject matter. Understanding the possibilities of multiple methods, beliefs, and ideas about science can aid teachers in preparing students for success in a pluralistic world. Just as bears do not exist in one environmental scene in the wild, students do not learn only in the engineered and standardized classrooms. Learning takes place in a plurality of locations and environments. "The landscapes of pluralism should be the main focus of a science education centered on preparing students to make informed choices and fully participate in society in ways that are reflective, reliant, and reciprocal of Earth's many natural environments that sustain life itself" (Mueller and Bentley 2007, p. 332). Science education must not only come from one source – the textbook – but also be studied in relation to students' lives. Pluralism represents so much more than ideas and methodologies; pluralism involves cultures and diversified ways in which humans live and experience their lives through multiple realities. These multiple realities lead to multiple understandings.

Cross-References

- ▶ Constructivism
- ▶ Science Studies
- ▶ Sociology of Science

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Postcolonialism in Science Education

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Keywords

Colonialism; Neocolonialism

Postcolonialism

Postcolonialism is a term that is used to help describe how institutions of the dominant cultures of the world in the global north work to devalue and ignore the self-knowledge of cultures of the global south. This self-perpetuating pattern of inequality and privilege is challenged in postcolonial frameworks where it is understood that “Knowledge is inherently questionable, and when the institutions of . . . science are working well, it is persistently questioned. It is the foreclosing of questions, and thus the end of the learning process, that defines the moment when science turns into ideology and its ideas become state, corporate or institutional dogmas” (Connell 2007, p. 228). Postcolonialism is about being prepared to engage in the unlearning of privilege.

Being privileged concerns how the institutions of the global north (the minority world) claim the right to name the world on behalf of the global south (the majority world), to build theories using economic and political power and control “on the experience of the most privileged 600 million people, then assume it accounts for the whole 6,000 million who are actually in the world” (Connell 2007, p. 212). To name the world in your own language is to understand and describe it a particular way and thus have control over it.

Postcolonialism is a perspective from which to question and critique, challenge, and transform the processes of colonialism and neo-colonialism. The issues addressed include who is permitted to speak, under what conditions and for what political purpose, and how knowledge is constructed and translated within and between various cultures existing within asymmetrical relations of power. Postcolonial theory, in its many varieties, seeks to create strategies for other ways of describing the nature of the world and to rethink what counts as knowledge in a context of respect for all intellectual traditions.

The Processes of Inscribing Privilege on the World

A postcolonial perspective involves a study of the historical processes by which power is disseminated and maintained. This perspective allows us to examine the grand narratives of colonialism/imperialism with their agendas of expansion, progress, and enlightenment: colonizing nations deliberately and systematically renamed, devalued, ignored, and silenced knowledge systems of the cultures they colonized.

For the black peoples, there is only one destiny, and this destiny is to be white (Fanon 1952). Fanon argued that white colonial cultures equated blackness with inferiority and impurity which then shaped the self-view of those who were subject to imperial authority: the black person’s soul is a white person’s artifact – to be black is to be the creation of patterns of fundamentally racist European thought.

There are two indivisible foundations of imperial authority – knowledge and power (Said 1978). The most formidable ally of economic and political control, Said argues, has long been the business of “knowing” other people because this “knowing” (in the sense of constructing them) underpinned imperial dominance and became the mode by which they were increasingly persuaded to know themselves – as subordinate to Europe. In a recent edition of *Orientalism*, Said points out that imperial narratives have had little trouble reinventing themselves in the political and economic context of globalization with its transnational corporate organizations embedded in an ideology of neo-colonialism (Said 2003).

Promoting corporate capitalism, this ideology supports economically devastating, culturally homogenizing, and ecologically destructive activities in vulnerable communities. Implementing planned policy imperatives of industrial nations of the north to maintain their influence in countries of the south, neo-colonialism is a continuation of the past practices. Supported by digital communication technologies purporting to be politically and ideologically neutral, neoliberal globalization policies spread via the Internet are examples of unequal exchanges that rely upon assumptions of cultural equity.

Education, like other commodities, is imported from the north to the south in the market-driven global economy, and this involves the imposition of northern administrative models and curriculum and assessment patterns for schools, foreign “experts” to ensure correct implementation, and a reliance on expatriate teachers, particularly at secondary and tertiary level. Indigenous education patterns are destroyed as “institutions like schools, universities and governments, through their assimilation regimes of standardisation and power laden rituals of credential granting, have proven remarkably good at epistemological homogenisation and the creation of a global monoculture” (Gruenewald and Smith 2008, p. 140).

The “Northernness” of Science: Describing Privilege

In her critique of northern science from a postcolonial standpoint, Sandra Harding argues that the term “science” is embedded in a positivist epistemological framework and is usually understood to refer only to the production of knowledge in the global north. This understanding promotes a belief of supposed objective methods used to construct supposed value neutral knowledge. Northern science is promoted as being culture free, and repeated claims are made regarding privileged notions of universal relevance. That is, northern science considers itself to represent universal knowledge and a coherent and unified representation of nature’s order (Harding 2006).

From a postcolonial perspective, universality is about epistemological disenfranchisement involving a process of selection and erasure, dispossession, and exclusion. This cultural hegemony is based on a myth that nature is knowable in the same way and from the same point of view, ignoring powerful connections between politics, economics, culture, and pedagogy. What is at issue is that it does not seem to occur to the north to doubt the universality of its own science, based on an assumption that cultural and epistemological hegemony does not matter (Harding 2006).

Writing from an African experience, Paulin Hountondji (Connell 2007) describes how, since colonial times, while scientific data is gathered and applied in the colonies, the theorizing happens in the global north. The resultant theory is distributed through a global network of institutions from the World Bank down, including universities, scientific organizations, journals, and the juggernaut of international foreign aid.

From a self-appointed position of privilege, the north argues that other knowledge systems do not deserve the name “science” because of their cultural elements, and they cannot be integrated into a harmonious or unified relation with northern science (Harding 2006). It is not unusual to find indigenous knowledge systems described as being nothing more than irrational, anthropocentric, and primitive thought of the other that is “intellectually discredited, dropped from curricula of schools and universities, or ripped off by corporations pursuing intellectual property rights” (Connell 2007, p. xi).

Questioning Northern Privilege

When the north does acknowledge indigenous knowledge systems, it is on the north’s terms. Paulin Hountondji insists that ethnoscience (the academic discipline that tries to reconstruct non-western cultures’ views about the natural world) represents a European gaze on indigenous knowledge. He argues that it is necessary to be concerned with the relevance, value, and local meaning of indigenous knowledge and the reasons why it is bound up with the so-called myth and magic (Connell 2007).

It can be argued that knowledge is not a matter of correctly representing the world (Rorty 1979). Rorty suggests that knowledge is not so much a way of mirroring nature as a matter of conversation and social practice. When we decide what counts as knowledge, our judgment rests not on how strongly a “fact” correlates to the world so much as whether it is something that society “lets us say.” What we can and cannot count as knowledge is therefore limited by the social contexts that we live in, by our histories, and by what those around us will allow us to claim.

Similarly Sandra Harding argues that the distinctive social and political history of the development of modern sciences is not external to the content of these sciences – “the very best supported scientific claims and practices, no less than false beliefs, are caused by social relations as well as by nature's regularities and the exercise of human reason. . . permeated by historically and culturally local values, interests, discourses and choices about how to organise the production of scientific knowledge. . . which aspects of nature modern sciences describe and explain, and how they are described and explained have been selected by conscious purpose and unconscious interests. . ." (Harding 2006, p. 43). Therefore, there is no sense of absolute rightness or wrongness to be discovered. The sciences we have are not inevitable; they are currently agreed upon fictions that are open to transformation. Transformations that will help us take into account the cultural elements that limit our understanding of the world.

Liminal Spaces and Unlearning Privilege

The notion of a liminal space, a space of possibility, comes from the word *limen* meaning the threshold, any place or point of entering or beginning. Liminal spaces are rich in reflexive potential. Reflexivity, like epistemology, does not address what we know but how we think we know. It is a process of arousing our self-awareness and, from a postcolonial perspective, we must inevitably confront our own processes of interpretation. It can be a space of risk as we engage with new possibilities in relationship with others.

Liminal spaces are not about bringing together or reinscribing the old hegemonies, rather they are about an opening up between and around each other. Working at the very frontiers of our intellectual selves and our understandings, we make visible our most cherished values, not to find a common meaning but to find a means of communication where the greatest differences can be expressed simultaneously.

At an epistemological level, we embrace empathetic practices of entering the imagination of others and learn to hear different voices. We must relinquish our privilege and dominant ways of knowing and learn to understand what it might be like to experience and see the world as others see it. It requires a language for describing frailty, humility, uncertainty, paradox, and contradiction.

Postcolonial Places in Science Education

Educators must interrogate how centers of power and privilege are implicated in their own politics and articulate the situated nature of their own personal beliefs, based on an understanding of the limits, partiality, and particularity of their own politics, values, and pedagogy (Giroux 1993). Educators must possess a theoretical understanding, beyond the positivist approaches to teaching supported by current neoliberal curriculum, to identify the ways in which difference is constructed through various representations and practices that name, legitimate, marginalize, and exclude the voices of subordinate groups.

A postcolonial pedagogy of place is an attempt to create something new from the liminal spaces of between. Our relationship to place is constituted in alternative stories as the primary unit of knowledge, and these stories shape our relationship with different places (Somerville et al. 2009). Pedagogies of place are local and embodied, challenging the objectifying strategies of "science" that separate us from our connections and relationships with the natural world. They critique decontextualized content approaches that fail to interrogate the conceptual frameworks and practices of Eurocentric philosophies and how these sciences have guided and made them appear not only reasonable but also the only such reasonable kinds of science (Harding 2006).

Pedagogies of place make explicit the philosophical, sociological, and historical assumptions that form part of scientific understanding about nature. Learning occurs where subjugated knowledges and northern science knowledge make contact. Every time we make a representation in our places, it is understood to exist besides a proliferation of other representations. Postcolonial "place making comes to be understood in terms of creating the conditions of meeting rather than the provision of a theoretical backdrop to prescribed social activity" (Carter 2009, p. 25).

Cross-References

- ▶ Cultural Imperialism
- ▶ Culture and Science Learning
- ▶ Indigenous Knowledge
- ▶ Values and Western Science Knowledge

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Postmodernism in Science Education

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Keywords

Postmodernity

Postmodernism possibly is the most misunderstood and most widely abused term that exists in our language. There are likely to be as many definitions of and opinions about postmodernism as there are people in a gathering. Given this wide variation, it is not surprising to see the concept itself being identified with confusion, fuzziness, and anything goes. Most fundamentally, as the name suggests, it is a reaction against modernism, itself associated with a set of ideas often denoted by the term metaphysics. The "post" in postmodernism is meant to mark the attempt to overcome modernism without retaining any of its forms of thought, which would be the case if postmodernism were merely a negation of modernism. At its heart, postmodernism is the attempt to think the flux of life, though this point gets often lost in the debate.

History of Modernism

In pre-Platonic Greek thought, the idea of life as a pervasive, never-ending (Heraclitean) flux was actively discussed. Thinking flux requires concepts that are very different from those that denote ideas, which have a thinglike character. With Plato, who shaped the dominant stream of Western philosophical thinking, the world accessible to human experience was but a shadow of another, non- and therefore metaphysical world. These ideas were said to determine human speech and behavior, which were merely an expression of underlying intentions. This form of thinking came to be formalized to its limit by the philosopher Immanuel Kant, who suggested that cause–effect thinking as a fundamental category of thought.

Cause–effect thinking underlies all technology and modern sciences; it also underlies almost all theories of human cognition. Given that postmodernist forms of thought question the very existence and usefulness of cause–effect thinking, it may not come as a surprise that there is actually very little work being done in science education related to postmodernism, which may be in part due to the antithetical nature of postmodernism, on the one hand, and science education practice and major theoretical approaches used in research, on the other hand. Karl Marx was one of the first to oppose such ideas, suggesting that the metaphysicians had everything confused, because it is not consciousness (and mind) that determines life but it is practical life that gives rise to human consciousness. It may not surprise either that scientists and engineers are vehemently opposed to postmodernism, even though they do not tend to understand very well what the term stands for.

Critique of Modernism

Friedrich Nietzsche was the first to launch a major attack on modernist thinking, providing detailed analysis of why cause–effect thinking is inherently false because, in the flux of life, causes cannot be determined until the effects are known. But because effects are not known until after the event has been finalized, causes can be determined only after the event and never before or during. He also showed that as soon as cause–effect thinking is abandoned, common notions of the agential subject have to fall, as well as common notion of objects as stable entities. Other ideas crumble, including those pertaining to the body/mind and mind/matter distinctions. What is gained are the continually unfolding life, language, and learning, that is, everything that is in process.

Seed of Postmodernism

Martin Heidegger pursues this kind of thought in his texts that are critical of technology, a fact often misunderstood to be an animosity toward the latter when in fact Heidegger's concern was with the underlying form of thinking merely epitomized in technology. He proposed difference in itself as a way of thinking being, which is inherently in flux. It is precisely these ideas about difference in itself that became to core of the philosophical developments that now are clustered together under the banner of postmodernism. Thus, for example, Gilles Deleuze takes up Nietzsche's agenda to theorize the flux of life in terms of repetition, which is never the same because that which is repeated already is different within itself. Jacques Derrida introduces concepts such as that of *writing*, which is based on the idea of writing on a magic pad, where new writing both erases what had been written on it before and keeps it simultaneously as a trace. As a result, as Jean-Luc Nancy suggests, no two persons are the same; there is only one aspect that everyone in a culture shares, which is that she/he is different from everyone else. The Russian (language) philosopher Mikhail Bakhtin, who has had some impact on science education, fundamentally takes the same position – even though precisely those ideas are yet to be taken up in science education.

Postmodernism in Science Education

If such ideas were taken up in science education, this would mean the abandonment of the agential subject, who constructs knowledge and identity; it would mean giving up the cherished notions of knowledge and knowledge structures that somehow can be accessed and assessed; and it would mean giving up issues such as the attribution of responsibility for what happens in the classroom to the sole person of the teacher. It would also mean giving up the belief that learning could be planned ahead of time and it would give up attributing agency to the teachers (or students) in the acquisition or construction of knowledge. To date, there possibly is only one real attempt to articulate the implications of such forms of thought in science education (Roth 2008). It shows that other cherished theories – e.g., agency/structure, border crossing, and third cultural space – are antithetical to this form of thought that has abandoned the centrality of cause–effect thinking. Taking up postmodernism also requires (re) thinking such issues as ethics, pertaining to the teaching–learning relations and to the relation between the products of science and technology and society.

Cross-References

- ▶ Borders/Border Crossing
- ▶ Identity
- ▶ Mindtools (Productivity and Learning)
- ▶ Poststructuralism and Science Education

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Poststructuralism and Science Education

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Keywords

Deconstruction; Poststructuralism; Signifiers; Structuralism

Poststructuralism is part of a larger cultural movement called "postmodernism," although poststructuralism is not synonymous with postmodernism. Structuralism first arose in cultural anthropology and quickly was adopted in other fields as researchers attempted to chart a middle ground approach to understanding human activity between the reductionism of natural science and the seeming subjectivity of phenomenology, existentialism, and psychoanalysis. Anthropologist Levi-Strauss and other structuralists, such as those in linguistics (Saussure), cognitive psychology (Piaget), and education (Bloom), approach all social systems as sets of regularities that an objective, ideologically neutral approach can discover and articulate. Structuralism further maintains that understanding these practices is possible if one assumes that the meaning of these practices exists entirely within the social structures under study and thus can only be approached as part of the patterns and relationships that form the systems. Within each pattern, structuralists argue, exist abstract "rules" of behavior that can be discovered and articulated, called "codes" and categories, or "signs" that form the constitutive elements of the system.

Structuralist approaches pervade modern educational systems in such areas as curriculum development, cognitive psychology, and planning lessons using taxonomies of educational objectives (Cherryholmes 1988). Teachers and students are assumed to exist as signs of relationships; for example, teachers "implement" the curriculum and students learn what is taught. Certain forms of knowledge, such as science, are considered to be legitimate "subjects" of the school curriculum and are standardized and constructed as a series of steps all children, more or less, can take to achieve a supposed understanding of concepts, whether in science or in any school subject. The meaning of this system exists within itself; for example, "doing an experiment" in science education holds meaning for the students, teachers, and the designers of the experiment, and structuralist approaches to science education assume that this meaning can be used to make revisions to the experiment as a learning activity. What is assumed is that all signifiers such as "teacher" or "student" or "experiment" embody standard meanings.

A central tenant of structuralism is that the truth about systems can only be discovered from within the system itself. Poststructuralism began as some philosophers argued that this claim is paradoxical since anyone approaching a system outside that system must, from a structuralist perspective, be part of their system and thus invariably bound up in the meanings they bring to their analyses. The structuralist assumption is thus self-defeating since one can never discover an "objective" meaning within any system other than one's own, and even this assumption is suspect since the structures we see may not be the structures seen by others; constructivist research in science education demonstrates this point very well. Individual variability in the experience of reality is further compounded by the lack of reliable representation of the signs in a system. Rather than a direct relationship between a sign and what it signifies, poststructuralism observes that the signs are defined through reference to other signs, creating what philosopher Jacques Derrida described as an endless chain of deferred meaning. From this point of view, there is never any clear, unequivocal meaning in any system, and the structures that exist to make up the system – even the idea of the system itself – are historically and politically constituted, mobile, and therefore not part of any particularly objective reality. What passes then as "knowledge" or "truth" operates to maintain and provide impetus for particular relationships that in themselves are not true or even knowledge in any transcendent, universal sense (Foucault 1980). For example, structuralists might point to the signifier "science student" and then, assuming that this category exists, talk about types of science students, even proposing a categorization of these students. Poststructuralists are deeply suspicious of such categorization because it first depends on assuming a transcendent, objective meaning to the signifier "science student." But what is assumed here in this combination? Does being a science student assume a concomitant relationship with a teacher? Is someone exploring the algae in a local pond by dipping a stick into the water "doing science" or is science only learned in the context of students/teachers/schools? We might assume the signifier "science education" is school-based, but why do we move to this assumption? Is the meaning of science education ever fixed? If not, and poststructuralists argue this position, poststructuralism presents a series of challenges to what operates under the sign of "school science education."

Three Poststructural Challenges to Science Education

Poststructuralism is skeptical of any approach that considers school science a system that can be articulated and analyzed for curriculum development and change (Blades 1997). There is, from a poststructural perspective, no "truth" about science education, or anything for that matter, that might direct change. Second, poststructuralism challenges and undermines notions of progress and positive growth in knowledge, even though this assumption underpins the entire history of science as presented in school science education. For example, why does school science education assume the development of atomic theory was a type of "progress"? We might counter by suggesting that such knowledge has assisted in the development of chemistry, medicine, etc., which in fact defers the response to another set of signifiers (such as "medicine") but does not really answer the question. From a structuralist view, the question seems absurd; of course it is "better" to have more information about the natural world. The poststructuralist challenge is to define "better" and even to challenge the fundamental notion of knowledge itself. This third challenge strikes at the very raison d'etre of science education since poststructuralism also deconstructs the very notion of science as an objective study of nature (Weaver et al. 2001). Poststructuralism advanced the now common argument that observation is never a culturally neutral act but instead situated in the flow of historical and political antecedents and current discourses, a point well established by historian of science Thomas Kuhn. In this way, poststructuralism challenges that what is produced by "modern science" as "knowledge of the world" – instead, poststructuralists note that other ways of seeing and understanding the world exist. For example, a wolf might be *Canis lupus* from the perspective of modern scientific taxonomy, but what is categorized as a "wolf" in this schema might in some Aboriginal cultures instead be considered a reincarnated ancestor. Science might argue that this moves knowledge into superstition, but poststructuralist thought challenges such simple dichotomies as "science" and "superstition." Poststructuralism does not play favorites: the knowledge produced, shared, and passed along in Aboriginal cultures is also subject to poststructural critique – all signs presented as "knowledge" falls under the gaze of poststructural deconstruction, including acknowledging the irony of its own sign as "post"structuralism.

The End of Poststructuralism

Poststructuralism undermines through relentless questioning the fundamental assumptions that support and maintain what we call "science education" by denying any transcendent meaning of this term for all and any participants in the discourses indicated by this signifier. This presents a serious challenge to all approaches to institutionalized schooling and curriculum change in science education. Even more difficult is the deconstruction of knowledge claims of modern science as truth about how the world was, is, and could be, presenting questions about the very foundational premise of science education.

While this relentless questioning can be useful as a kind of cultural mirror, we are left with a serious and urgent challenge: How can we establish a sense of ethics and understanding, albeit always tentative, of ourselves with/in the universe? Poststructuralism has no response to this essential and important question, suggesting only a somewhat nihilistic elusiveness to all meaning. While poststructuralism may thus contribute to an increased humility and a return to admissions of tentativeness in science theorizing, humankind will need to turn from the relentless yet barren critiques of poststructuralism to discover possibilities for a hopeful science education.

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▶ Postcolonialism in Science Education
▶ Postmodernism in Science Education

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Practical Work

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Keywords

Apparatus; Equipment; Experiment; Hands-on; Laboratory; Manipulatives; Minds-on

While practical work is a ubiquitous feature of science classrooms, the term is used in a variety of ways. Sometimes referred to as "prac" or "pracs," the expression is typically describes hands-on activities or investigations involving scientific equipment or apparatus. In secondary settings, practical work can range from formal procedural "experiments" taking place in a school science laboratory to more student-centered, inquiry-based activities. In primary or elementary classrooms, practical work often involves students working with more concrete everyday materials. In this context, teachers may refer to students' use of "manipulatives" to explore scientific phenomena. In recent years, educators have offered a number of critiques of practical work (see "▶ Laboratories, Teaching in"), emphasizing the importance of balancing hands-on activities and minds-on engagement with the underlying principles behind the activities.

Cross-References

▶ Experiments
▶ Laboratory Reports

- ▶ Laboratory Work, Forms of
- ▶ Laboratory Work: Learning and Assessment
- ▶ Laboratories, Teaching in

Practicum/School Experience/Fieldwork

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Keywords

Fieldwork; Practicum; Science teacher education

Practicum and Teacher Education

Practicum experiences are widely recognized by prospective teachers and teacher educators as one of the most valued and integral elements of any teacher education program. Regardless of context, this perspective is ever-present and central to learning to teach science (Russell and Martin 2007). It is during the practicum when many teacher candidates self-assess their own suitability for teaching and their place in the profession. Practicum can be considered an all encompassing term used to describe field and clinical experiences in schools. Typically these practicum experiences are organized by a teacher education institution and involve a stand-alone field experience course or are an academic requirement for a science methods course.

Depending on the program, these school-based field experiences can occur throughout a program of study, and traditionally a science teacher education program culminates with a prolonged practicum experience during the teacher candidate's professional or preservice year. These experiences primarily involve (i) student teaching and (ii) internships. In the former, teacher candidates are given significant responsibility in a classroom, under the supervision of a certified teacher, for science planning and instruction and are expected to develop and demonstrate professional competence in an authentic context involving elementary and secondary science students. For the latter, teacher candidates are expected to be engaged observers of professional practice while assisting and co-teaching with an experienced mentor science teacher. While practicum experiences can vary in terms of activities and duration, ultimately, these experiences consist of a period of observation, modeling, teaching, reflection, and critique with the supervision of an experienced science teacher – typically referred to as an associate or cooperating teacher. The key to the success of these orientations is the multiple roles played by associate teachers. They play an integral role in supporting a novice science teacher's initiation into the teaching profession.

Many teacher education programs use practica for multiple goals depending on the overall mission of the teacher education program. In some jurisdictions there are accrediting organizations, for example, the Council for the Accreditation of Educator Preparation (CAEP) in the United States, which identifies professional standards for accreditation of teacher preparation programs and stipulates that institutes provide practicum experiences for all science teacher candidates. Clark (2002) identified four major purposes of practicum for teacher education programs: (a) experimental component for the teacher education program, (b) long performance evaluation, (c) apprenticeship in teaching, and (d) opportunity to practice inquiry-oriented teaching. While not mutually exclusive, each of these purposes has its own conceptual and philosophical backdrop.

Learning During Practicum

During a practicum, science teacher candidates are expected to integrate academic and practical knowledge of science teaching by observing an experienced teacher and also demonstrate their capabilities as a teacher by student teaching in a school context. During these experiences important outcomes are learned which are crucial to their development as science teachers. One of the fundamental outcomes for prospective science teachers is the managing of materials and students in a science classroom or laboratory. This includes organizing students in small groups or a large-group format and also managing science equipment, information and communication technology, and other materials for students in a safe and effective manner while they learn biology, chemistry, physics, and earth sciences.

Another integral experience is based on student-teacher interactions. Here, teacher candidates typically learn about assessment techniques for student feedback (e.g., questioning) and how to use effective discourse with students in a laboratory and classroom setting. Teacher candidates integrate both pedagogical and disciplinary knowledge in order to effectively plan lessons for science students. In order to effectively construct pedagogical and practical knowledge, science teacher candidates need opportunities to self-reflect on their teaching goals and science students' learning outcomes. Associate teachers are vital to this as they can contextualize and support teacher candidates during this often tumultuous time. Academic faculty advisors also play an essential role to facilitate learning from these practicum experiences.

Challenges

One of the challenges facing teacher education is the lack of coherence or alignment between practicum and science teacher education courses (Korthagen and Kessels 1999). That is, the relationship between academic and applied learning during practicum is not fully conceptualized or enacted. When courses (e.g., science methods courses) are aligned with practica, an opportunity exists to support prospective science teachers in meaningful learning and implementing innovative practices learned from an academic setting. For instance, when science teacher candidates have an opportunity to explore a 5E instructional model for teaching science concepts, ideally they should have an opportunity to see it modeled by their associate teacher and practice implementing this instructional strategy in a science classroom. However, many logistical challenges (e.g., academic course timing) and mitigating factors (e.g., associate teacher support) deter many institutions from providing seamless experiences for teacher candidates from course work to practica. General efforts to narrow this gap include having multiple practicum experiences and by establishing a -school-university partnership. However, many innovations in science teacher education have focused on short-term impacts on teacher candidates, either implemented during their time at the university or in a single practicum session in schools.

Linking Academic and Practical Learning

Another attempt to better bridge academic learning and practicum-based experiences is by changing the actual model for teacher preparation. Indeed, there have been a number of reform proposals over the last few decades that have focused on altering structural design features in teacher education programs. Not surprisingly, these reforms have resulted in important impacts on science teacher candidates. One example is by organizing science teacher education programs using a professional development or partner school model, where there is a formal articulation between a practicum school and university regarding the components of a teacher education program (Schoon and Sandoval 1997). This has produced important impacts for both novice and practicing science teachers in school settings. In this model, teacher education faculty and associate teachers share roles and responsibilities for the entire science teacher education program and mutually benefit from the program.

Another model involves science teacher candidates and university faculty advisors themselves co-participating with the science teacher candidates and associate teachers in the teaching of science in schools (Tobin et al. 2001). This model blends the traditional theory-practice dichotomy found in many teacher education programs. Some institutions have extended practicum experiences to augment learning to teach science by organizing internships in informal science education settings. Museums, aquariums, and after-school or science camps are all settings that contrast with formal school science contexts, yet offer enhanced learning opportunities for science teacher candidates.

What all these models emphasize is a recognition that learning from practicum experiences needs to be central to learning how to teach science. Importantly, academic faculty must be involved to support science teacher candidates to effectively explore and understand their field experiences in schools and find new perspectives that are theoretically informed. With this said, all aspects of teacher education must operate in concert to equip science teachers not only with a rich repertoire of instructional techniques but also the skills and general disposition needed to engage in effective science teaching. The practicum component plays a pivotal role in this process – but it must be properly designed to do so and implemented within settings appropriate to achieving these objectives.

Conclusion

Regardless of its importance to science teacher candidates, the research on practicum experiences and teacher learning is still limited. Future study examining the impact of practica on novice science teachers' views and practices is required. This research should seek to investigate practica across a variety of school settings, including different science subject areas, and explore the effectiveness of different practicum models.

Cross-References

- ▶ Pedagogical Content Knowledge in Teacher Education
- ▶ Pedagogy of Teacher Education
- ▶ Primary/Elementary Science Teacher Education
- ▶ Secondary Science Teacher Education
- ▶ Teacher Research

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Primary/Elementary School Science Curriculum

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"Curriculum" is a word used with different meanings: some referring to a written document which sets out what is to be taught and/or what is to be learned and some to the full range of experiences that affect what students learn. This entry adopts the first of these and is concerned with the content of documents that set out intended learning experiences and expected learning outcomes across the years of schooling, in this case the first 6 (in some cases 7) years of formal education. Using this approach means that the pedagogy through which the learning goals are to be achieved is something for teachers, curriculum projects, and program developers to decide. Examples of these two components of curricula form the main sections of this entry, following a brief review of the background and rationale for teaching science from the start of formal education.

Background: The Roots of Primary Science

Before the major changes beginning in the 1950s and 1960s, science was included in some elementary schools in Western countries largely as a result of the actions of a few inspiring scientists and educators in the nineteenth century. For example, in the UK, H E Armstrong, T H Huxley, and other members of what was then the British Association for the Advancement of Science campaigned to broaden the range of topics and methods of teaching beyond the only form of teaching about the natural environment that was then practiced – the “object lesson.” In these lessons teachers followed a dull routine of showing an object (which might be a piece of coal) and asked questions about it that often called for memory rather than observation. Armstrong promoted the heuristic method of learning through discovery, based on a view of scientific knowledge as being developed inductively from sensory experience. Although helping to promote a more active role for the children in their learning, both the philosophical underpinning of heurism and its practicability made it difficult to defend.

At the beginning of the twentieth century, support for change in the whole ethos of primary education was being promoted in many developed countries through the writings of educators such as Dewey, Montessori, and Homer Lane, building on the earlier ideas of Froebel and Pestalozzi. The ideas they advanced came to be described as “progressive” education. However, in practice little changed for several decades due to the impact of the First World War, the depression in the early 1930s, and then the Second World War and its aftermath. Indeed in England it was not until 1994 that the change from all-through “elementary” education to separate primary and secondary for all children, advocated in the late 1920s, was finally enacted.

Rationale

Teaching science in the primary and elementary schools has been justified in different ways. In the 1920s and 1930s, science was advocated as part of the progressive movement and a response to children’s curiosity and interest in finding out about the world around, although with little effect in the vast majority of schools. The postwar period saw a groundswell of support for active learning and the inclusion of science in the primary curriculum. More practical reasons were also being voiced, stemming from the widespread concern about the poor state of science education and its failure to keep up with the scientific and technological developments during and after the war. In response to this concern, attention was first given to renewing secondary school science, but it was soon realized that such science as there was in the primary school was failing both in developing pupils’ understanding of the scientific aspects of the world and in preparing them for secondary science education.

There was some resistance to regarding primary science as a preparation for secondary science and the most strongly supported arguments were concerned with the benefit to the children during their primary school years. The predominance of such views can be seen later in the report of an international meeting of primary science educators held by UNESCO in 1980 which listed the main reasons for primary school science. These included:

- The development of an enquiring mind; promoting children’s intellectual development, including thinking in a logical way and problem solving
- Improving the quality of children’s lives
- Assisting in other subject areas, especially language and mathematics
- Equipping children for living in an increasingly scientific and technological world
- Learning science can be “real fun”

Most of these claims were based on little more than wishful thinking or the response of enthusiasts to the novel activities in the early science projects. Even though there was hardly any research evidence for them, such arguments were used in support of giving science a place in the primary curriculum. Interestingly primary science was embraced sooner in less developed countries than in developed countries where there was more skepticism about unsubstantiated claims. Thus in the early 1970s, alongside and often drawing upon projects in Western countries, there were projects sponsored by ministries of education and often with the help of organizations such as the British Council, UNICEF, and UNESCO and in Sri Lanka, Israel, Brazil, Indonesia, Singapore, Lebanon, Sudan, Saudi Arabia, Bulgaria, India, and many African countries.

The Impact of Research

Such research in primary science as there was in the 1970s was mostly concerned with the impact of the new curriculum materials on teachers and teaching, revealing far lower levels of uptake than expected. With regard to impact on pupils, studies which compared different curriculum projects with each other or with traditional teaching from textbooks found no significant differences in pupils' scientific achievement, although some US studies reported an increase in questioning and process skills as a result of using new materials.

Stronger reasons for beginning science at the primary level have emerged from research into students' conceptual development. Studies of the ideas that students hold about the scientific aspects of the world became a major focus of research in science education in the 1980s. Many of these ideas – at first called "misconceptions" and later described as "alternative frameworks" or "children's ideas" – were in conflict with accepted scientific views. Research in many countries revealed remarkably consistent patterns in secondary students' ideas, which were the initial focus of attention. The ideas of primary and middle school students were studied, particularly by researchers in New Zealand, Greece, the USA, and England. These studies revealed a range of ideas about the scientific aspects of their surroundings that children had developed from their limited experience and ways of thinking. For example, children commonly describe the process of seeing as if it is their eyes that produce the light that enables them to see. When asked to show how they see an object, they draw and describe a ray of light directed out of the eye to the object along the line of sight. This is an understandable interpretation of the subjective experience of "looking" and a persistent and widespread conception, which can interfere with later learning.

How children come to form these ideas has been suggested by the research into very young children of preschool age and babies, revealing intense mental activity in the preschool years. So it is not surprising that children enter school with some ideas already formed about how things in the physical and biological world "work." Their ideas about the natural world are developing from birth and throughout the primary years whether or not they are taught science. Without intervention to introduce a scientific approach in their exploration, many of the ideas they develop are nonscientific and if these persist they may obstruct later learning.

As well as helping students to a better understanding of aspects of the world around them, it was argued that starting science in the primary school had benefits to society. These follow from young people developing understanding of key ideas that enable them to make informed choices about, for instance, their diet, exercise, use of energy, and care of the environment. Equally the development of scientific skills and attitudes can support a growing appreciation of the role of science in daily life.

Towards National Curricula

In the absence of national, regional, or district curricula, that is, before the 1980s, what was taught at the primary level was largely guided by the materials produced by projects. The early primary science projects promulgated different views of science and what was to be achieved in learning science. Some gave priority to the development of an inquiring mind, to problem-solving capability, and to logical thinking, promoting a view of science as a process of inquiry, while others prioritized the development of major science ideas. The rather extreme positions of these early projects soon gave way to more balanced views, acknowledging the interdependence of the use of scientific processes and thinking and the development of understanding of science concepts (Harlen 2008).

The diversity of content and to some extent of approaches was curtailed once national, regional, or district requirements were established. In many countries the trigger for setting out agreed aims was the desire to assess what students were learning, assessment practices being poorly developed at that time. National and international projects of assessment in science, such as NAEP in the USA, the APU in England, and the IEA program of surveys, required frameworks for what should be learned and assessed.

A curriculum document describes at a general level the intended learning across the relevant age range. There are generally two kinds of statement:

- Inputs, or what is to be taught – giving a broad overview of progression, set out year by year or in for "stages" of schooling
- Outcomes, or what is to be learned – specifying outcomes for the purpose of assessment, described in various ways, such as "learning outcomes," "performance expectations," "standards" (as in the USA), "attainment targets" (in the English curriculum), or "achievement standards" (in the Australian Curriculum).

In some curricula, statements of what is to be taught are combined with learning outcome statements in one document; in others these are quite separate and often created by different agencies, concerned variously with the content and with assessing learning. There is also a considerable difference in what is included, according to whether or not the implementation of curriculum is required by law or has only the status of "guidelines." Non-statutory documents can contain guidance and exemplars of teaching methods, without infringing the role of the schools to decide matters relating to pedagogy.

These curriculum statements cover the whole age range of compulsory schooling, primary and secondary. The next two sections focus on what is included about the intended input and outcomes in the primary/elementary school years.

What Is to Be Taught

Statements of what is to be taught invariably include reference both to inquiry, or process, skills and to content or "knowledge and understanding" to be mastered. In most cases these are listed separately. The National Curriculum for England (DfE 2013) for the primary school is a typical example. It specifies under the heading "Working Scientifically" skills and processes such as planning investigations and obtaining and evaluating evidence. The rest of the program of study lists various content topics relating to the disciplines of biology, chemistry and physics. For the skills there are statements of what "pupils should be taught" during years 1-2, 3-4, and 5-6 and for the content areas what is taught in specified for each year. Thus some threads of progression can be discerned, but there is no overall discussion of progression in these areas, as there is, for instance, in the USA *Framework for L-12 Science Education* (NRC 2012). This has three dimensions:

- Scientific and engineering practices (e.g., planning, carrying out investigations)
- Crosscutting concepts (e.g., patterns, systems, energy flows, and cycles)
- Disciplinary core ideas (physical, life, Earth and Space sciences, and applications of science)

For the first two of these, the framework identifies particular practices and crosscutting concepts and describes the course of development. This leads to a summary of what students should know by the end of grade 12 rather than a more detailed description for grades along the way. For the core ideas, however, intended achievement at the end of grades 2, 5, 8, and 12 are identified, as in the example in Box 1.

The Australian science curriculum (ACARA 2012) also has Science Inquiry Skills and Science Understanding as two separate strands, with Science as a Human Endeavor as a third. Science Understanding is divided into four sub-strands – biological, chemical, earth and space, and physical sciences with the content in each being specified year by year.

Box 1: Grade Band Endpoints Relating to "Structure and Function in Organisms" from A Framework for K-12 Science Education (NRC 2012)

By the end of grade 2. All organisms have external parts. Different animals use their body parts in different ways to see, hear, grasp objects, protect themselves, move from place to place, and seek, find, and take in food, water, and air. Plants also have different parts (roots, stem, leaves, flowers, fruits) that help them survive, grow, and produce more plants.

By the end of grade 5. Plants and animals have both internal and external structures that serve various functions in growth, survival, behavior, and reproduction.

By the end of grade 8. All living things are made up of cells, which is the smallest unit that can be said to be alive. An organism may consist of one single cell (unicellular) or many different numbers and types of cells. . . .

Identifying Progress

The years of primary education, from age 5 to age 11 or 12, span a period of considerable cognitive change. During this time students gradually move from being characteristically egocentric to being able to take another's point of view, from thinking that is closely related to action towards the mental manipulation of ideas and the formal thinking that most will achieve later in the middle or high school years.

Science curricula endeavor to promote progression in learning by setting out learning outcomes at various stages. Ideally these should be based on evidence of how learning typically proceeds. The assumption that this is a step-by-step progression underpins the proposed sequences developed by the 2001 AAAS Atlas of Science Literacy and some of the research into "learning progressions." How justifiable it is to try to specify for all students what is to be learned before the next step can be taken depends on how closely the outcomes are specified. In some cases what is to be learned is set out year by year and in others only in terms of achievement at the end of longer periods of 2 or 3 years. The closer the specification, the more problematic the decisions about the exact sequence and the greater the risk of the detail obscuring sight of the overall aims – the overarching powerful ideas and the skills of scientific inquiry. The statements of the specific ideas and skills that students are expected to learn ought to be justifiable in terms of progression towards these overall aims. Such a structure provides for consistency across the primary-secondary boundary since at all times the overall aim is to progress towards the same overarching ideas. When this structure is not made explicit, the content of a curriculum can appear to be no more than an arbitrary selection of what is to be taught, based on tradition or what is easily assessed.

Specifying Learning Outcomes

Given the widespread view that inquiry skills and concepts should be taught in an integrated way, their separate specification in curriculum documents seems unhelpful. Yet expressing the interdependence of process and content in setting out what is to be learned is a continuing challenge for curriculum designers. In most science curriculum documents, the separate specification of skills and content in the overall framework is carried through in the separate specification of learning outcomes.

The English National Curriculum identifies the statements in the program of study, of what pupils are expected to know, apply and understand, as the attainment targets to be achieved during years 1 and 2, 3 and 4, and 5 and 6. Box 2 gives these statements for "working scientifically".

In the Australian curriculum achievement standards are specified for each year. The outcomes for Science Understanding are brought together with those for Science as a Human Endeavor in a single paragraph but remain separated from outcomes for Science Inquiry Skills. Box 3 gives examples for Years, 2, 3, and 4.

The Scottish *Curriculum for Excellence* departs from this separate specification by expressing goals at different points, roughly 3 years apart, as a combination of process and content, described as "experiences and outcomes" (see Box 4).

A similar combination of different dimensions is proposed in the draft Next Generation Science Standards (NGSS 2012) based on the K-12 Science Education framework in the USA. Although the framework, as mentioned earlier, does not specify year-by-year outcomes for the three dimensions (scientific practices, cross-cutting concepts, and disciplinary core ideas), the NGSS are specified for each year within topics, as in Box 5. The topics are related to the core disciplinary ideas in the framework.

As these examples show, the primary school science curriculum is still developing, as practice and research reveal more about progression towards key science ideas and about the role and nature of inquiry skills.

Box 2: Attainment Targets for "Working Scientifically" in the National Curriculum for England (DfE 2013)

During years 1 and 2:

- Ask simple questions and recognize that they can be answered in different ways.
- Observe closely, using simple equipment.
- Perform simple tests.
- Identify and classify.
- Use their observations and ideas to suggest answers to questions.
- Gather and record data to help in answering questions.

During years 3 and 4:

- Ask relevant questions and use different types of science enquiries to answer them.
- Set up simple practical enquiries and comparative and fair tests.
- Make systematic and careful observations.
- Gather, record, classify, and present data in a variety of ways to help in answering questions.
- Record findings using simple scientific languages, drawings, labeled diagrams, etc.
- Use results to draw simple conclusions, make predictions, etc.
- Identify differences, similarities, or changes related to simple scientific ideas and processes.

During years 5 and 6 (end of primary school):

- Plan different types of scientific enquiries to answer questions, including recognizing and controlling variables where necessary.

Box 3: Achievement Standards of the Australian Science Curriculum for Science

By the end of Year 2, students describe changes to objects, materials, and living things. They identify that certain materials and resources have different uses and describe examples of where science is used in people's daily lives.

Students pose questions about their experiences and predict outcomes of investigations. They use informal measurements to make and compare observations. They follow instructions to record and represent their observations and communicate their ideas to others.

By the end of Year 3, students use their understanding of the movement of the Earth, materials and the behavior of heat to suggest explanations for everyday observations. . . . They describe how they can use science investigations to respond to questions and identify where people use science knowledge in their lives.

Students use their experiences to pose questions and predict the outcomes of investigations. They make formal measurements and follow procedures to collect and present observations in a way that helps to answer the investigation questions. Students suggest possible reasons for their findings. . ..

By the end of Year 4, students apply the observable properties of materials to explain how objects and materials can be used.... They describe relationships that assist the survival of living things and sequence key stages in the life cycle of a plant or animal. They identify when science is used to ask questions and make predictions. They describe situations where science understanding can influence their own and others' actions.

Students follow instructions to identify investigable questions about familiar contexts and predict likely outcomes from investigations. . .. They suggest explanations for observations and compare their findings with their predictions. They suggest reasons why their methods were fair or not. They complete simple reports to communicate their methods and findings.

Box 4: Experiences and Outcomes for "Biodiversity and Interdependence" in the Scottish Curriculum for Excellence (2010)

Early stage (end of first primary year) I have observed living things in the environment over time and am becoming aware of how they depend on each other. I have helped to grow plants and can name their basic parts. I can talk about how they grow and what I need to do to look after them.

First stage (end of fourth primary year) I can distinguish between living and non-living things. I can sort living things into groups and explain my decision. I can help to design experiments to find out what plants need in order to grow and develop. I can observe and record my findings and from what I have learned I can grow healthy plants in the school.

Second stage (end of primary school) I can identify and classify examples of living things past and present, to help me appreciate their diversity. I can relate physical characteristics to their survival or extinction. I have collaborated in the design of an investigation into the effects of fertilizers on the growth of plants. I can express an informed view of the risks and benefits of their use.

Box 5: Examples of the Draft USA Next Generation Science Standards

Grade 2 Standards for structure, properties, and interactions of matter

Students who demonstrate understanding can:

a. Evaluate natural or designed objects to explain how the properties of the materials suit different purposes.
b. Collaborate with others to design an object built from a small set of pieces to solve a technological problem.
c. Provide evidence that some changes caused by heating or cooling can be reversed and some cannot.
d. Measure and compare the physical properties of objects.

Grade 3 Standards for interactions of forces

Students who demonstrate understanding can:

a. Investigate the motion of objects to determine observable and measurable patterns to predict future motions.
b. Investigate the motion of objects by comparing the relative sizes and direction of forces on an object at rest to the forces on an object whose motion is changing.
c. Use models to explain the effects of balanced and unbalanced forces on a system.
d. Investigate the forces between two or more magnets to identify patterns.
e. Investigate the push-and-pull forces between objects not in contact with one another.
f. Design and refine solutions to a problem by using magnets to move objects not in contact with one another.

Cross-References

- ▶ Curriculum
- ▶ Curriculum Movements in Science Education
- ▶ Primary/Elementary School Science Curriculum Projects

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Primary/Elementary School Science Curriculum Projects

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The first projects to publish materials to support science education in the primary school (students aged 5–12) began in the 1960s. Since that time many hundreds of curriculum projects in primary school science have been developed in countries across the world. The ideas and materials produced in many of these projects can be traced to certain influential projects, which are the focus of discussion here. These key projects occurred in two main waves, the first ones beginning in the 1960s and the second about 25 years later.

Projects of the 1960s

In the USA three science projects for primary school students began working at the same time in the early 1960s. They differed in structure and were based on contrasting views of science and learning. The *Elementary Science Study* (ESS 1966) provided a range of activities that enabled students to work scientifically, based on the argument that children are by nature questioning and enjoy solving problems. The activities they described emphasized the development of scientific processes, such as observation, planning and conducting investigations, and interpreting data. Although the content was related to science concepts, the program was unstructured in relation to concept development. There was an emphasis on using simple, everyday materials, but where special materials were required, they were provided in a class kit.

The approach of *Science – A process Approach* (SAPA 1967), as its title suggests, was also process based but, in contrast with

ESS, was highly structured. It identified the processes in two groups. Those appropriate for young students were as follows: observing, using space-time relationships, using numbers, measuring, classifying, communicating, and predicting. Once students had developed these, other processes were added: interpreting data, formulating hypotheses, controlling variables, defining operationally, and experimenting. The materials for teachers – there were no student texts – took the form of booklets each focusing on a specific process, sequenced by grade.

The *Science Curriculum Improvement Study* (SCIS 1967) aimed to develop students' understanding of the nature and structure of science. The intention behind the classroom materials was to give the students sufficient knowledge and experience "so that they will be able to have some understanding of scientific work being carried out by others, even though they themselves do not become scientists. This quality we have called scientific literacy" (Karplus and Thier 1967, p. 30).

To this end the material was organized around several major scientific ideas, such as systems, material objects, interaction, relativity, and organisms. The material for teachers took the form of units relating to these major ideas. Units set out objectives and explicit instructions for teaching, including what to tell students. Equipment kits were developed for the units and there were booklets for students.

In the UK two projects began in the early 1960s. These differed in focus on process or content as did the projects in the USA. One was a research and development project in primary science, the *Oxford Primary Science Research Project*, funded by the UK Department of Education and Science and set up 1963. It produced a book for teachers on how to develop students' ideas relating to four major overarching concepts – energy, chance, structure, and life. This project had little impact and is only noteworthy on account of its focus on concepts, in considerable contrast to the second project. The Nuffield Junior Science (NJS) project, set up as part of the Nuffield Science Teaching Program, began in January 1964 with the rather different aims of "producing children who are keenly observant, questioning, able to devise means of getting answers to their questions, scientifically rigorous and can communicate." To achieve these aims the project gave the teacher maximum flexibility and no student materials or kits of equipment were produced. One of the books for teachers described a range of activities for students presented in the form of case studies. The material was unstructured and there was no attention given to a coherent development of science concepts.

A project which followed NJS, although based on a similar child-centered view of primary education, provided greater structure. This was *Science 5/13* which, during its 8 year life, provided a statement of "objectives for children learning science" to help teachers work purposefully, 26 units for teachers giving ideas for children's activities related to children at three stages of development, and information about the background science for the unit topics.

Beyond the USA and the UK, other countries were establishing their own science projects. The program of development in Africa, the Science Education Program for Africa, included the *African Primary Science Project* which produced 52 short topic-based units for teachers, a handbook for teachers and a sourcebook for teacher trainers. The approach taken had much in common with *ESS* and *Science 5/13*, providing ideas for classroom activities around topics but leaving decisions about the choice and sequence of students' activities to the teacher. Some African countries developed their own program with more structure, seen as necessary in view of the low level of many primary teachers' own education. The northern states of Nigeria based their primary program on a modified list of SAPA processes, organized into a 6-year course.

Revision of existing projects and development of new ones continued throughout the 1970s. At the same time it became evident that changing practice, towards more active learning, was a difficult and long-drawn out process. Problems were exacerbated by most primary teachers' poor knowledge of and attitudes towards science.

Studies of implementation in both developed and developing countries found that the curriculum projects were having little impact beyond a few enthusiasts. Moreover, economic downturn in the late 1970s delayed the efforts that further development required.

Projects of the 1980s and 1990s

In the 1980s, in both the UK and the USA, reports on the state of education exposed a cause for concern. In England the 1978 report of a survey by HM Inspectors of Schools, *Primary Education in England*, noted that few classes visited "had effective programmes for the teaching of science." The UK government firmly endorsed the place of science in its policy document *Science 5-16*: *A statement of Policy* of 1985. In the same year a project of research was begun, funded by the Nuffield Foundation, into the science concepts of primary students, the *Science Processes and Concepts Exploration* (SPACE) project. After the National Curriculum was introduced in England and Wales in 1989, requiring the teaching of science in primary schools, the research was extended to cover the range of concepts included at the primary level and became the basis for the major science curriculum project of the 1990s, *Nuffield Primary Science* (NPS). The NPS materials comprised a set of teachers' guides, short booklets for students, and guides for coordinators and in-service leaders, linked to the National Curriculum. Based on a constructivist approach to teaching and learning, students' activities start with exploration of materials or events during which teachers elicit the ideas the students have about phenomena related to the topic. The guides give examples of students' ideas derived from the SPACE research and suggestions for taking these ideas as starting points and helping the development of more scientific understanding.

In the USA the 1983 report *A Nation at Risk* revealed that less than 1 % of school districts had effective science education programs. One response to this was the creation in 1985 by the Smithsonian Institution and the National Academies of the National Science Resources Center (NSRC). A key aim of the NSRC was to produce programs and support for science teaching based on research into how to bring about change in schools as well as how to develop students' conceptual understanding. NSRC produced the project *Science and Technology Concepts* (STC) for elementary and secondary schools, with supporting classroom and professional development materials and kits of equipment. Meanwhile the Lawrence Hall of Science produced *Full Option Science System* (FOSS). Its third edition was published in 2012 to reflect the National Research Council's Framework for K-12 Science Education. FOSS materials include teacher guides, equipment kits, science stories for students, videos for teachers, and an assessment system. A further project, *Insights*, was produced by the Education Development Center. This modular program for elementary science is organized around six major themes similar to the themes of SCIS. The hands-on experiences are carefully sequenced in the 21 modules, providing a structured approach for teachers to follow.

The projects in the USA, particularly *STC* and *Insights*, influenced developments in the 1990s in other countries. In France, a trial in 1996 of some *Insights* modules led to the development of the project *La main à la pâte* (*LAMAP*), *supported by the French Academy of Sciences*. The project has been in constant development since that time, producing a wide range of materials, a support network and a website that provides over 300 classroom activities, documents on science teaching, and online access to scientists to answer teachers' questions. The teaching approach is based on a sequence of stages within a lesson designed to develop science concepts and inquiry skills. It is expected that science occupies a minimum of 2 h per week and that each student will keep a notebook describing their work in their own words.

LAMAP has set up pilot centers in many countries in Europe, Latin America, and Southeast Asia. The project's resources are made freely available and have been adapted, for example, in China, in creating the Learning by Doing project, and in Brazil, Colombia, Serbia, Cambodia, and Senegal. In Europe, the inquiry-based approach to science education and some materials of LAMAP have been spread through the Pollen and Fibonacci projects, involving 24 countries of the European Union.

The STC project has also been disseminated to Mexico, Chile, and Sweden and used in developing these countries' own elementary science programs. The Swedish project, Natural Science and Technology for All (NTA), was begun in 1997 as a project of the Swedish Royal Academy of Science. It has been expanded and developed and since 2003 is managed by a cooperative of schools and municipalities, each having an NTA coordinator. This arrangement ensures that the kit of materials required for each unit is provided when needed and when a unit is completed the kit is returned to a center for refurbishment ready for another class.

Many of the post-1990 projects combine science with technology and engineering. By contrast, in England, the National Curriculum treats science and technology as separate subjects, and this has led to different projects being created for science and technology.

Most recent projects pay attention to the use and development of students' language skills both as means to cognitive development and ends in themselves. In Australia, the Primary Connections project makes this a major focus, aiming at developing students' knowledge, skills, understanding, and capacities in both science and literacy. It promotes an inquiry approach through a five-phase lesson structure, 5Es: engage, explore, explain, elaborate, and evaluate. Thirty-one units provide activities for students in each year from kindergarten to year 6 in physical, chemical biological, and Earth and space sciences. An associated professional learning program helps teachers to understand the program and adapt and extend the units.

Cross-References

- ▶ Assessment of Doing Science
- ▶ Assessment: An Overview
- ▶ Curriculum Movements in Science Education
- ▶ Formative Assessment
- ▶ Summative Assessment
- ▶ Validity and Reliability of Science Assessments

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Primary/Elementary Science Teacher Education

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Keywords

Primary schools; Teacher Education; Teachers

What Is Primary Science?

It is universally accepted that learning science is important for the future lives of all citizens. Therefore, science as a required part of primary and secondary education has become commonplace in most countries. As children have a natural inclination and creativity for science and the world surrounding them, one expectation of teachers is the need to develop the skills for catching students' ideas and stimulating their questioning and their (scientific) reasoning. However, research illustrates that there has been a common concern about primary teachers' lack of scientific knowledge which has been seen as a major barrier to developing quality science teaching and learning in primary schools. Today, primary teachers' scientific knowledge is widely recognized as having improved, but there is still world-ranging debate about the level and nature of scientific knowledge needed by a primary teacher in order to teach science effectively.

There is a lot of international research that indicates that students' interest in science declines in the early postprimary years, while other studies suggest students' positive attitudes towards science increase within primary level. There is global recognition of the problem of decreasing interest in school science. Reasons for the situation include such things as the content-driven nature of the science curriculum, the perceived difficulty of school science, students' difficulties in seeing the relevance of science, and the role science plays in society and children's everyday world as well as home-related and social-related factors. Other reasons suggested for this decline in interest include a lack of practical work in science, nonspecialist teaching, and overemphasis on practice assessments for national tests.

It has been suggested that teachers in general and perhaps primary teachers in particular need knowledge and skills to stimulate students' enthusiasm in science and also that the lack of continuity and progression between primary and postprimary science should be addressed by bringing primary and postprimary schools together to devise "bridging units" between primary, postprimary, and secondary school. Hence, arguments about rethinking science in primary schools and across the primary-secondary school transition in forming students' attitudes towards science are well supported.

Over the last decade, several countries have experienced government interventions leading to reforms of teacher education programs and national school curricula for all levels. As a consequence, new curricula for primary science have raised discussions of primary teachers' scientific knowledge and attitudes towards, and confidence in, teaching science. Primary teachers are faced with the need to teach several subjects, and coping with their shifting roles in different subject matters suggests a need to have content knowledge in all these different subject areas. However, as science in primary schools is often taught in an integrated setting, estimating the amount of science taught in terms of hours per week is difficult. Science in primary school is often described as a broad subject made up of many domains. As such, the question as to what counts as science in primary schools is important in shaping the way activities are planned and organized in the primary classroom. Further, the evidence and arguments that support the role of science in the primary curriculum must be recognized in order to ensure that *what* and *why* science is taught also matches the learning intentions.

One strong argument for science in the primary curriculum is that children's ideas about the world develop throughout their primary years whether or not they are taught science. Without any intervention, many of the ideas they develop are nonscientific and may in fact confuse their learning of science phenomena in future education (Harlen and Qualter 2009). Further, students' interest in sciences, in most cases, is formed early, often in primary school, yet that interest tends to drop quickly in physics, chemistry, and technology in the early secondary school years. Therefore, another argument for introducing science in the early primary years is to stimulate students' interest, engagement, and attitude towards science.

At a primary level, activities generally begin from objects and events connected to the students' everyday experiences. In describing "big ideas" in science, Harlen referred to progression towards key ideas which together enable understanding of events and phenomena of relevance to children's lives during and beyond their school years. Harlen argues that science big ideas should have explanatory power in relation to a large number of phenomena that are encountered by students in their lives. They should provide a basis for understanding issues involved in making decisions that affect their own and others' health and well-being, the environment, and their use of energy. They should also provide enjoyment and satisfaction in being able to answer or find answers to the kinds of questions that people ask about themselves and the natural world. Finally, these science big ideas should have cultural significance – for instance, in affecting views of the human condition – reflecting achievements in the history of science, the inspiration from the study of nature, and the impacts of human activity on the environment. These big ideas have a strong relevance for primary education, the beginning point for studying science in the formal classroom setting.

It is well argued that important features of provision for learning science in primary years are the development of inquiry skills; the opportunity to observe and investigate familiar objects, materials, and events; and the opportunity for students to talk to each other or to the teacher and to express their existing ideas and develop them in the light of new information gathered either from their practical investigations or observations. However, sometimes the focus of activities in the (primary) classroom might put emphasis on what the students will be *doing* to the detriment of that which they are intended to *learn*. Therefore, a crucial role of primary science is "to build a foundation of small ideas that help children to understand things in their immediate environment but, most importantly, at the same time to begin to make links between different experiences, and ideas to build bigger ideas" (Harlen and Qualter 2009, p. 39). To do so, teachers need to gather information about children's inquiry skills and ideas of science and use it to help them achieve their goals and move on.

Developing Student's Ideas of Science

Children, even when very young, have ideas about the world around them, and these ideas play an important role in their learning experiences. They come to school with different ideas about certain phenomena and concepts even though they have never had any formal instruction on these concepts. Children form their conceptions on the basis of their everyday life and experiences (Driver et al. 1985) and build up their scientific knowledge from a range of sources outside the school environment. One way of developing, engaging, and challenging students' ideas of science is through the notion of scientific literacy.

Scientifically literate people are interested in and understand the world around them; engaged in the discourses of and about science; able to identify questions, collect data, and draw evidence-based conclusions; skeptical and questioning of claims made by others about scientific matters; and able to make informed decisions about the environment and their own health and well-being. A shift in the emphasis of primary science education towards scientific literacy requires careful consideration on behalf of teachers and as such dedicated time and structures for reflection and spaces to experiment and play with ideas. If teachers in primary school work with these skills to develop students' ideas of science, they may well form a basis for future citizens who will engage with science at a personal and a societal level and therefore offer a springboard for understanding science so often sought in the educational community.

Many primary teachers indicate that science is the subject they least enjoy teaching, in part because they are afraid their teaching will uncover ideas they do not understand and cannot explain to students. The challenge of addressing students' ideas shows that even though primary teachers believe that knowing about and addressing students' ideas is important, these beliefs are not always confirmed in their instruction. Teachers' ability to respond to ideas depends on different factors such as teaching experience, content knowledge, and access to materials. When teachers do not understand the concept, it is avoided, or not addressed, during instruction. On the other hand, research also indicates that teachers often feel challenged to acquire the resources needed to create science learning environments that stimulate students' scientific reasoning.

Helping students to change and develop their ideas of science is based on the assumption that students are willing to express their ideas. If they do not feel that their ideas are valued, they are less likely to share them publicly. One way of probing students' understanding about science concepts has been through the use of "Concept Cartoons." A Concept Cartoon shows different characters arguing about the answer to a question or debating alternative explanations of scientific phenomena using many of the well-documented misunderstandings, as well as correct understandings. As such Concept Cartoons can be used to stimulate discussion before, during, or at the conclusion of an investigation. In a primary school context, students can use these Concept Cartoons to develop their ideas of science, to structure debates, and to articulate reasons for selecting one explanation over another.

Harlen and Qualter (2009) suggested that learning in science is generally viewed as a process of developing and changing children's ideas as opposed to *giving* them the ideas. Before a teacher can gain access to children's ideas, it is necessary to establish a classroom climate in which children feel that it is safe to express their ideas and in which their ideas are valued and taken seriously.

One way of creating such a safe learning environment and probing students' ideas and inquiries used in an Australian primary school context is called the "wonder wall" (Nilsson 2011). The "wonder wall" is a wall on which students place different questions about scientific concepts and phenomena. These questions could be "what is a shadow?," "how does medicine work?," and "what happens when we get ill?" Even though the wonder wall is used as a way of uncovering students' ideas, it is well worth noting that not only the students but also teachers can put their questions on the wall. The reason for this is explained by a primary teacher when he stated that he wanted his ". . . students to understand that as a teacher [he] also ha[d] inquiries and as a teacher [he] do not always know all the important facts or bits of information" (Nilsson 2011, p. 136).

As mentioned above, an important aim of primary science is to stimulate students' curiosity about the world around them, to develop their ideas of science, and to encourage critical and creative thinking. To fulfill this aim, students need to acquire both factual knowledge and the skills of identifying questions that can be addressed scientifically. Young children need to experience the world around them. However, students may appear to be enjoying an activity but really be more entertained than engaged in learning. Seeing beyond a fun activity can therefore be a catalyst for more sophisticated thinking about science teaching and learning in primary schools. This requires activities that go beyond simple sensations to students developing their ideas, raising questions, planning how to obtain evidence, predicting what might happen, and thinking about how to capture and share their findings. In order to develop this complex set of skills, students need to go beyond being told about science but instead explore their ideas through interactions and practical inquiry. For these learning experiences to occur, primary school teachers' knowledge and skills are crucial.

Teaching Primary Science: Teacher Knowledge and Self-Confidence

Research into teachers' knowledge and beliefs of teaching and learning has been shown to have a great impact on classroom practice. Several studies have shown the connection between teachers' science knowledge and confidence in teaching science. Even though there has been some progress in developing teacher confidence in primary science over the last 10 years, the situation has not dramatically changed.

While a small minority of primary teachers have undertaken science studies, significantly, few have specialized in studying science. Further, many primary teachers have had little or no success in their own study of science, which influences their attitudes towards, and self-confidence in, teaching science. Another challenge for primary teachers has proven to be the lack of previous experiences with hands-on science or inquiry activities in their classrooms. Other reasons as to why primary teachers lack confidence in science teaching have been insufficient subject knowledge, lack of experience in science practical investigations, and lack of access to equipment or support for organizing equipment. There is also the possibility that primary teachers do not have a view of the nature of science knowledge that would provide insight into how science can stimulate productive learning experiences for students.

The low confidence of primary teachers often results in teaching that is limited to “science activities that work” that involve only science content with which the teachers feel familiar. Further to this, a commonly noted problem in preservice primary science education arises from the situation that the majority of preservice teachers do not have a genuine interest in science. Olson and Appleton (2006) highlighted that method courses that provide science inquiry activities and stimulate student teachers to discuss how science content could be explained to students have a great influence on student teachers’ attitudes and skills in successfully beginning teaching primary science.

Although the findings of a number of studies have indicated that science method courses can be successful in developing positive attitudes towards teaching science, increased science knowledge by itself will not consistently result in improved self-confidence. As new teachers often feel anxious about conducting science experiments with students, there is a need for student teachers not only to develop their subject matter knowledge but also to see how the knowledge is meaningful in a primary school context.

Students’ attitudes towards science are influenced by teachers’ behavior in the classroom such as asking challenging questions, portraying the essence of a scientific approach to students, and stimulating their enthusiasm and interest. But this is difficult when the teachers themselves are uncertain of the subject content. Hence, an important issue for both preservice and in-service teacher education is to consider how to increase primary teachers’ interest for, and engagement with, teaching and learning science.

Many studies into subject matter knowledge (SMK) emphasize that teachers cannot explain the principles underlying physical phenomena to their students if they do not explicitly understand them. Teachers need to understand the structure and nature of their discipline, have skills in selecting and translating essential content into learning activities, and recognize and highlight the applications of the field to the lives of their students. For successful primary teaching, teachers need the capacity to transform the content knowledge they possess into forms that are pedagogically powerful. For developing such capacity, it is important to create conditions for practical experiences in primary science teaching that are reasoned and reflected upon.

Primary science, for example, through a scientific literacy approach, can work to help students develop different skills, to engage in discourses of and about science, and to understand the world around them. Through science activities, students can develop the necessary skills to drive their inquiries of a science topic in meaningful ways. They can reflect on and respond to ideas and find evidence to describe science knowledge, facts, and information. In such a way, science activities can provide a purpose for learning through drawing, singing, reading, writing, questioning, and reasoning.

In order to promote such learning processes, teachers need to be aware of strategies for helping students to understand the language of science. Children’s questions and ideas in science can further be used as tools to influence primary teachers to confront their own thinking about science content in order to improve their own knowledge. An important aspect of primary teaching is not to “tell” the right answer but to help students see the purpose in why they learn things and the way they can use that knowledge in their everyday lives. Therefore, revising the role of the primary teacher from being the supplier of all the right answers to a facilitator or lead learner is crucial for beginning to move towards developing good science teaching and learning in primary schools. That is the challenge that confronts Primary School Science teaching today.

Cross-References

- ▶ Curriculum in Teacher Education
- ▶ Pedagogical Content Knowledge
- ▶ Primary/Elementary School Science Curriculum
- ▶ Science Teachers' Professional Knowledge

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Print Media

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In this entry, "Print Media" will refer to agents of various means of mass communication that use print as the primary form of interaction. "Communication" will mean those science communications directed towards the general public, towards science students at particular grade levels, scientists in a particular field, and members of the public with keen interests in science. "Print" will refer to the written word and to other forms of literate communication, such as graphs, charts, tables, and diagrams that can be combined with the written word in science communications. The technology for displaying the print – paper, film, computer screens, smart phones – is not relevant to this discussion. Specifically, the entry will not be about science communications in which the spoken word plays a primary or large role, such as conference presentations or workshops. Although conference presentations and workshops often are accompanied by print, the print usually is not independent of the oral presentations. In the print media that is the focus of this entry, the science communications are self-contained and, at least in principle, can be understood without aural input.

Print media communicate science in a variety of forms. This entry will address the following: primary scientific literature, journalistic literature (newspapers, science magazines, the Internet), and educational literature (textbooks, trade books, adapted primary literature). The Internet is a special case because it contains all of the forms in which science communication occurs. We group it with journalistic literature, and when we speak of the Internet, we mean only those communications that fit with the journalistic category, although we recognize that the Internet contains print designed for educational purposes. Also, e-book forms of textbooks and trade books are considered equivalent to the paper forms for discussing the characteristics that are examined in this entry.

Primary Scientific Literature

Primary scientific literature is written by scientists, for scientists, and appears in specialized scientific journals – scientific periodicals – and books. Primary scientific literature appears in a wide array of forms to match the large number of types of scientific research. Many pieces of primary scientific literature report studies in which data were collected and used as evidence to draw conclusions. Some primary literature does not present new data but draws upon data reported in other studies in order to support a new conclusion. Primary scientific literature need not present data at all but can report theoretical research – sometimes using mathematics – that proposes a view of how some aspect of the world works. The theory might then be used to predict that under certain conditions certain events would be observed to occur, or might be used to explain known events that have gone unexplained for some time. Sometimes data reported by primary literature derives from experiments, other times from surveys or from observational studies. Always, primary scientific literature is technical, requiring specialized knowledge to fully understand (Myers 1991). Always, primary literature is argumentative, making a case for a conclusion either on the basis of evidence or on the basis of reasons drawn from theory or logic. Primary literature describes scientists' best efforts to communicate their reasoning. As such, primary literature is incomprehensible or only marginally meaningful to those without specialized education in the field.

Journalistic Literature

Under the heading of journalistic literature are included newspapers, science magazines, and the Internet (with the restrictions described above). Journalistic literature typically has some basis in primary scientific literature, by relying on the primary literature as an authoritative source, and adapts the information for a purpose different from that of the primary literature (Jiménez-Aleixandre & Federico-Agraso 2009). One frequently occurring type of adaption is to present the results of primary scientific literature without the evidence and reasons for those results. A second type of adaptation is to speak to the practical implications of the research findings and to tie why the research was done to these practicalities, a topic that might not have appeared at all in the primary literature. A third sort of modification often included is a human interest angle to the research, often some anecdote from the lives of the scientists who conducted the research or some connection between possible implications of the research and particular persons whom the results might affect.

The results of these adaptations are texts that are primarily expository in structure – attempting to relate events and situations as they are – compared to primary literature, which is mostly argumentative in nature, attempting to defend conclusions. However, studies have shown that argumentation occupies on average about one-fifth of the space in individual newspaper and magazine science articles and can occupy as much as nearly one-half the space. It also has been found that the statements in journalistic literature generally are presented as true (on average about two-thirds of the time) with little hedging. However, up to one-fourth of the statements in individual pieces of journalistic literature are presented as uncertain. In primary scientific literature, hedging is the norm. Comparable figures for the Internet are not available, but the Internet's enormous diversity would suggest that the reader of science communications there could expect to find at least the range of characteristics found in newspapers and magazines.

The result for the reader is that a wide range of interpretive skills and strategies are needed for accurate understanding of science communications found in journalistic literature. First, we need to recognize the characteristics of most science students. Interpreting narrative is their greatest strength. Interpreting exposition and description is less fully developed, but is strong in some people. Interpreting argumentation is the least developed of all. Many readers think of reading simply as word identification and information location. Science educators need to recognize the misinterpretations students are likely to make and the remedial action that can be taken to help them. Hedges are likely to be missed, so students need to be taught to look explicitly for them. Causes are likely to be confused with correlations, and descriptions of phenomena and proffered explanations of them are likely to be treated in the same way; so students require practice in distinguishing these different aspects of meaning. Also, students need to be made aware of their bias towards certainty, and to be taught strategies to help them recognize the uncertainty and tentativeness built into all genuine accounts of science. Finally, students need to be taught to take care with structure. They must be taught to keep separate the story line from the scientific description and from the argument. If necessary, these might need to be physically pulled apart into separate documents or separate parts of the one document. If there is argumentation, students should be shown how to make its structure paradigmatic – reason and conclusion juxtaposed – with indicator words: "because," "consequently," "therefore," and "however" supplied where they are missing from the original journalistic literature.

Educational Literature

Under educational literature designed to communicate science, we include textbooks, science trade books, and adapted primary literature, regardless of the technology used to present them.

Science Textbooks

Science textbooks are ubiquitous and have been studied extensively. From the earliest to the most advanced levels of science education, they tend to have the same general characteristics. Science textbook authors introduce various organizational features to help readers to comprehend tables of contents and indexes, learning objectives and overviews at the beginning of chapters, vocabulary lists with meanings, review questions at the end of chapters or sections, and visualizations. Science textbooks also introduce reading difficulties by presenting enormous quantities of information, frequently at a superficial level, which makes sense-making difficult, and accompanied by large amounts of new technical vocabulary, which places additional demands on comprehension.

Compared to journalistic literature, textbooks tend to contain an even greater proportion of expository text, virtually no argumentative text, and a small proportion (~10 %) of narration. Also compared to journalistic literature, textbooks generally state hardly anything as other than truth: there is little hedging and, to all intents and purposes, no tentativeness. This style of communication creates in students an expectation for truth and thus biases their interpretation strategies such that they tend to miss tentativeness and uncertainty when it is expressed. Textbooks concentrate on the facts and conclusions of science and not on how those facts were derived and conclusions reached. This concentration does not prepare students well for interpreting journalistic literature, which also devotes most of its space to facts and conclusions, but also spends significant time speaking about research methods and what motivated the research in the first place.

The number of visualizations in most science textbooks is very large. These visualizations range from photographs of people, places, and things to charts, graphs, and tables containing technical information and, to diagrams and figures designed to portray processes and objects not directly observable. Visualizations are intended as an aid to interpretation. However, research has shown that visualizations often are designed in such a way as to impede understanding. Furthermore, whereas the target audience for visualizations is often those students having difficulty learning science, it is those students with a firm grasp of science who learn the most from visualizations. Thus, science teachers are well advised to provide frequent and structured assistance to students to help interpret visualizations in science textbooks.

Science Trade Books

In the primary and elementary grades, trade books are often the preferred print media support for science instruction. Science trade books are literary books containing science content and are designed for a general readership rather than for the purposes of formal education (Ford 2005). Trade books provide both interesting possibilities and challenges for teaching science in school. The vast majority of reading instruction in schools takes place using narrative texts, and the reading strategies taught in that context are simply assumed to be applicable to expository and argumentative texts. To an extent, the strategies are generalizable, but also to an extent learning to read is genre specific. Science trade books are primarily expository in nature and thus fall into a type of text on which students have received less specific reading instruction (Norris et al. 2008). Thus, any difficulties in reading science trade books that arise from the genre of the books risk being associated in students' minds with science itself.

Other significant issues arise in the use of science trade books to teach science in schools. First, research has documented a bias among teachers to select life science topics almost to the exclusion of the earth and physical sciences. Second, given that science trade books typically were not designed as instructional resources, they provide little or no support for teachers in designing lessons. Third, in a manner similar to science textbooks, science trade books tend to concentrate on scientific content knowledge and mostly to ignore concepts of evidence, procedural knowledge, and the nature of science and scientific inquiry. Fourth, when the books focus on evidence, it tends to be upon direct observation, which runs the risk of intensifying a bias students are known to possess in taking as scientific evidence only that which is directly observable. Fifth, the development of scientific vocabulary is addressed in science trade books, and considerable new vocabulary is provided in them. Nevertheless, trade books rarely build upon the best and latest research on language acquisition, such as the need for repeated opportunities to use new words in context.

Science trade books can be useful sources of scientific information and vocabulary for use in educational settings. However, like science textbooks, they can portray a distorted image of the nature of science. Therefore, as with all educational resources for teaching science, they function best in the hands of teachers knowledgeable of the content and procedures of science, and of the pitfalls in learning this subject and how to navigate around them.

Adapted Primary Literature

Adapted primary literature is designed to overcome the problems faced by textbooks and trade books in the teaching of science. Adapted primary literature is an adaptation of primary scientific literature for use by science students that attempts to maintain much of the canonical form of the primary literature while making allowances for the level of scientific knowledge possessed by the students. In maintaining the canonical form of primary literature, adapted primary literature contains much more discussion of methods, fuller presentation of data, more extensive argumentation, and more widespread expressions of tentativeness than any form of print media other than primary literature itself. Adapted primary literature has much of the look and feel of primary literature. There are titles and authors listed at the beginning. There are discussions of findings including mentions both of the strengths and of the weaknesses of the studies. Often, there are arguments directed to impugn interpretations of the results alternative to the one presented.

Research into the use of adapted primary literature with elementary school and high school students shows that, as might be expected, the genre presents specific challenges. Students are not used to facing text in this form. Encouragingly, what the research does show is that students think more critically about adapted primary literature than they do about textbooks and journalistic literature (Yarden 2009). One conjecture for why this might be so is that adapted primary literature actually invites critique, much as science does, by its hedged and tentative mode of expression. This is a good result, because it demonstrates that when students are asked to read texts that resemble primary scientific literature, they start to read more like scientists. The risk is that tentativeness is seen as a shortcoming of science, so teachers cannot end instruction with just a naïve view of the fallibility of science. Students need to grasp how science can be uncertain and, at the same time, the most reliable source of knowledge available.

Conclusion

The ability effectively to use print media is crucial to the communication of science, whether for the one sending or the one receiving the communication. There are many forms of print media used in the communication of science, and each brings its own communicative strengths and its own interpretive demands.

Cross-References

- ► Broadcast Media
- ► Online Media
- ► Science Books
- ► Science Fiction

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Prior Knowledge

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Keywords

Diagnostic assessment; Prerequisite knowledge; Prior learning

The term "prior knowledge" is used in relation to teaching and learning and refers to the knowledge that a learner or group of learners has prior to a specific learning episode or course/program of study. The notion of prior learning is important from at least two perspectives. From the perspective of educational purposes, educational provision should be designed such that each stage or phase of educational experience allows learners to make progress beyond what they have already achieved in earlier stages or phases. So, for example, teaching about any science topic in secondary education should represent progression over what is taught in primary school. Similarly, an undergraduate program will be designed so that the curriculum for the final year students is more advanced than that met by freshers. The design of a curriculum therefore involves making decisions about appropriate target knowledge at each stage or level informed by assumptions about the prior knowledge of students studying at that stage or level.

A second, but related, perspective is that of the nature of the processes of learning. It is widely considered that academic learning is an iterative process, where learners use previous learning and experience as interpretive resources to make sense of new teaching and over time develop their existing understanding and knowledge through the process of relating existing knowledge to new ideas, examples, or contexts they meet in their studies. This is a basic assumption of constructivist models of learning. Analysis of science concepts, and research exploring students' ideas and possible learning progressions, suggests which prior knowledge is needed to meaningfully learn key concepts set out in the science curriculum (Alonzo and Gotwals 2012). That prior learning which is considered essential for making sense of a new concept is referred to as prerequisite knowledge.

Diagnostic assessment techniques, and sometimes published diagnostic instruments, may be employed by teachers to check whether student prior knowledge matches the identified prerequisite knowledge at the start of a topic or course of study and to check whether students have already learned material in the teaching scheme

(Treagust 2006). Where learners already show reasonable grasp of target knowledge, adjustments to teaching may be made to avoid repetition and to ensure progression in learning is possible. Where diagnostic assessment suggests prerequisite knowledge is absent, then either remedial tuition can be provided, or adjustments to teaching programs may be made to omit or defer concepts that students are not yet well prepared to learn. The importance of students' prior knowledge to the success of classroom learning is now widely acknowledged and is reflected in a much-quoted aphorism due to the educational psychologist David Ausubel (1968: vi): "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him [or her] accordingly."

A great many studies into student knowledge and understanding in science education have found that learners' prior knowledge about science topics cannot be considered simply in terms of the presence or absence of the prerequisite knowledge needed for learning the target knowledge set out in the curriculum. Research suggests rather that students commonly hold alternative ideas in many science topics that may overlap only partially or may even be completely at odds with prerequisite and/or target knowledge. These alternative ideas have commonly been labeled with various descriptors such as intuitive theories, misconceptions, alternative conceptions, and alternative conceptual frameworks. Research suggests that these alternative ideas are often significant for learning of target knowledge – frequently although not always in ways that interfere with intended teaching – and that they may at least sometimes may be tenacious and continue to dominate the learner's thinking about a topic after teaching of the canonical scientific ideas. Diagnostic assessment of prior knowledge is therefore an important part of science teaching with at least three important functions:

- To check that students do not already hold the target knowledge to be taught
- To test for the presence of essential prerequisite knowledge
- To identify alternative conceptions that may impede learning of canonical target knowledge

Cross-References

- ▶ Alternative Conceptions/Frameworks/Misconceptions
- ▶ Assessment to Inform Science Education
- ▶ Ausubelian Theory of Learning
- ▶ Curriculum
- ▶ Facts, Concepts, Principles, and Theories in Science, Assessment of: An Overview
- ▶ Formative Assessment
- ▶ Learning Progressions
- ▶ Teaching and Learning Sequences

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Problem Solving in Science Learning

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Introduction: Problem Solving in the Science Classroom

Problem solving plays a central role in school science, serving both as a learning goal and as an instructional tool. As a learning goal, problem-solving expertise is considered as a means of promoting both proficiency in solving practice problems and competency in tackling novel problems, a hallmark of successful scientists and engineers. As an instructional tool, problem solving attempts to situate the learning of scientific ideas and practices in an applicative context, thus providing an opportunity to transform science learning into an active, relevant, and motivating experience. Problem solving is also frequently a central strategy in the assessment of students' performance on various measures (e.g., mastery of procedural skills, conceptual understanding, as well as scientific and learning practices).

A *problem* is often defined as an unfamiliar task that requires one to make judicious decisions when searching through a *problem space* with the intent of devising a sequence of actions to reach a certain goal. *Problem space* is defined as "an individual's representation of the objects in the problem situation, the goal of the problem, and the actions that can be performed in working on the problem" (Greeno and Simon 1984, pp. 591). This exploratory nature of problem solving mandates an innovative, iterative, and adaptive process. In contrast, in an *exercise* the solvers apply a preset procedure, with which they are acquainted, to reach the problem's goal, and therefore the solvers' choices are limited (Reif 2008). Whether a task serves as a problem or an exercise for a particular solver depends on the prior knowledge of the solver.

School science problems share common traits that stem from their being grounded in a scientific knowledge domain: prediction is derived from well-specified premises and requires precision; real-world phenomena are simplified and their description is reduced to a few variables. Where appropriate, school science problems require the use of formal, explicit rules that are part of a scientific theory. These rules must be interpreted unambiguously, as compared with the plausible, implicit knowledge structures that serve in everyday reasoning. However, the problems typically used in science classrooms vary greatly along dimensions such as authenticity (i.e., abstract vs. real-world context), specifications of known and target variables (i.e., well vs. ill structured), duration (a few minutes to several months), complexity (i.e., the amount of intermediate variables), and ownership (i.e., the problem defined by the teacher or by the student). At one end of the problem spectrum, one can find the abstract, well-structured, short, and simple problems that are commonly found in traditional textbooks. At the other end, one can find design or inquiry projects that introduce a real-world context, are ill structured and complex, and involve the students themselves who define the project goals and who engage in extended investigations that they have roles in determining.

Domain-Specific Knowledge and Problem Solving

The relevance of research on problem solving to science instruction increased in the 1970s, when researchers began studying problems anchored in specific knowledge domains (e.g., chess, physics, and medicine). Some of this research focused on short and well-structured problems encountered in science classrooms, all of which require well-defined problem-solving procedures. This research originally took an information processing perspective. It involved two central methodologies: the analysis of "think aloud" protocols of both more and less experienced subjects (described in this research as "experts vs. novices") in a specific domain to determine how each group approached problem solving and the construction of computer programs to simulate and validate theories of human behavior in solving problems. Research on experts and novices has underscored the importance of domain-specific knowledge in problem solving, as well as the role of problem solving in developing domain-specific knowledge and general problem-solving methods.

Experts' and Novices' Approaches to Problem Solving

One aspect in which experts and novices in a certain domain differ is their prior knowledge structures and how they use these. When approaching problems, both experts and novices rely on specific cues (e.g., keywords, idealized objects, and previously encountered contexts) in the problem situation to automatically retrieve domain-relevant information. However, experts store in their memory hierarchical structures (schemas) of domain-specific knowledge (declarative and procedural) that allow them to use cues in problems to quickly encode information (chunking) and to reliably retrieve schemas. Experts' schemas revolve around in-depth features (e.g., underlying physics principles), in comparison with novices' problem schemas, which rely on surface features (e.g., "pulleys") and are fragmented. However, other researchers (Smith et al. 1993) who have taken a constructivist, "knowledge-in-pieces" view of learning argue that novices abstract deep structures of intuitive ideas rather than representations organized around concrete surface features.

When solving problems, both experts and novices were found to use heuristics – general but weak methods to enhance their search process, such as a means-ends analysis, starting from the problem's goal and working backward to the given problem situation, recursively identifying the gap between the problem or goal and the current state and by taking actions to bridge this gap. However, unlike novices, in describing a problem, experts devote considerable time to qualitative analysis of the problem situation before turning to a quantitative representation (Reif 2008). More specifically, experts often make simplifying assumptions, construct a pictorial or diagrammatic representation, and map the problem situation to appropriate theoretical models by retrieving effective representations that derive from the experts' larger and better organized knowledge base. In addition, experts differ from novices in their approach towards constructing the solution: while novices approach problems in a haphazard manner (e.g., plugging numbers into formulae), experts devote sufficient time to effectively plan a strategy for constructing a solution by devising useful subproblems. Experts also have better metacognitive skills and spend more time than do novices in monitoring their progress: they evaluate their solutions in light of task constraints, reflect on their former analysis and decisions, and revise their choices accordingly as necessary.

Problem Solving as a Learning Process

Problem solving may trigger a process of conceptual change, leading learners to develop scientifically acceptable *domain-specific declarative knowledge*. Namely, learners can refine and elaborate their conceptual understanding by engaging in problem solving in a deliberate manner: articulating how they apply domain concepts and principles, acknowledging conflicts between their ideas and counterevidence, and searching for mechanisms to resolve these conflicts.

Similarly, successful learners were found also to work in a deliberate manner when learning from worked-out examples. Worked-out examples in standard textbooks frequently omit information justifying the solution steps. Research (Chi 2000) indicates that learners tend to generate content-relevant articulations (self-explanations) to make sense of solution steps. Successful problem solvers generate more self-explanations and, in particular, principle-based ones. More specifically, they tend to relate the solution steps to the domain principles or elaborate on these principles. Self-explanations serve learning by either bridging the gaps that correspond to the omissions in the solution or by a self-repair process in which solvers attempt to resolve a conflict between the scientific models conveyed by a worked-out example and the possibly flawed mental model held by the solver.

Acquiring *domain-specific procedural knowledge* takes place when the problem solver, applying general but weak search methods, identifies successful domain-specific procedures that are stored for future use. These acquisition processes play an important role in designing e-tutors for problem solving. Another mechanism for acquiring domain-specific knowledge is the use of analogical reasoning in solving analogous problems that may be similar in one of two ways:

1. They may be similar in the material properties shared by the two problem scenarios (e.g., the heart and a pump). Devising an analogous scenario to an original problem scenario can help the solver to focus on relevant variables and identify a strategy to solve the original problem. Instructors have used intermediate scenarios, termed bridging analogies, to support the process.
2. Another type of similarity between two problems refers to the scientific concepts and principles that the solver employs to solve the problems. Solvers often rely on the procedure used in solving a previous problem (i.e., a source problem) and map it to construct a solution to a target problem (e.g., resolving the forces in a static equilibrium problem, where various force agents are considered).

Identifying clearly the similarities as well as the differences between analogous problems can help students to acquire domain-specific procedural and declarative knowledge.

Research underscores several factors affecting learning through problem solving:

- *Metacognition* relates to the extent to which within a problem-solving process the purposeful pursuit of learning, accompanied by an awareness of one's beliefs and goals, takes place.
- *Epistemological beliefs*, such as one's expectation to engage in a deliberate search process or merely to retrieve an algorithm to solve a problem, affect what learners notice and think about when they act.
- *The sociocultural nature of learning* highlights the contribution of cooperative learning that engages students in discussing and arguing their ideas when solving problems together.
- *Cognitive load* (Paas et al. 2010) results from the limitations of working memory, impeding meaningful learning when the solver has to process simultaneously vast amounts of information.

Instructional Methods for Fostering Problem Solving and Conceptual Change

The traditional teaching of science problem solving involves a considerable amount of drill and practice. Research suggests that these practices do not lead to the development of expert-like problem-solving strategies and that there is little correlation between the number of problems solved (exceeding 1,000 problems in one specific study) and the development of a conceptual understanding.

Cognitive apprenticeship underlies many instructional strategies that have been found to promote expert-like problem solving. During problem solving, learners interact with their peers and with their instructor and reflect on the connections between their existing ideas and practices and those that more closely characterize experts' culture of practice and decision-making. The roles of the teacher are (a) *modeling*, explicating the tacit problem-solving processes of the expert, (b) *coaching* learners as they engage in scaffolded problem-solving, and (c) *fading*, gradually decreasing this support until the learners can work independently.

Two complementary mechanisms of scaffolding problem-solving have been suggested (Reiser 2004): *structuring* and *problematizing*. *Structuring* a task refers to reducing its complexity and limiting the choices of the problem solver. *Problematizing* directs one's attention to aspects that one might otherwise overlook. Instruction should be balanced between structuring and problematizing so that tasks will be manageable to learners yet remain challenging and engaging. These mechanisms can be carried out for the range of problems described in the introduction.

The following are some examples of structuring methods that have been shown to be effective:

1. *Worked-out examples* can be used to "model" the tacit goals and reasoning underlying the problem-solving strategies of experts, which later can be used in students'

solutions. To narrow the problem space and minimize the cognitive load, researchers use methods such as labeling solution steps in terms of "subgoals." This approach has also been implemented in e-tutors that follow a *reciprocal teaching* approach, where computers and students alternately coach each other.

2. Tools that assist learners in applying heuristics when seeking solutions. For example, inquiry or design maps recommended for guiding a particular design or an inquiry project serve as visual aids that may help learners to decompose open-ended problems and track what steps they have taken in a problem solution.
3. Explicit verbal reminders (prompts) can induce problem solvers to formulate self-explanations and to self-repair their understanding.

Like structuring, problematizing also takes different forms along the problem spectrum previously mentioned. For example, researchers have pointed out the instructional value of problem situations that elicit intuitive ideas and result in confusion (e.g., qualitative conceptual problems) to trigger argumentative discussion. Problematizing in this context refers to techniques used to stimulate argumentation, such as asking students to express their ideas, encouraging them to identify gaps in their understanding and by providing the requisite time and social atmosphere so that they can work to resolve any disagreements. Incorrect examples (e.g., the teacher providing solutions she/he knows to be erroneous) were found efficient in triggering reflection and in highlighting critical features that distinguish between scientific and lay interpretations of the scientific concepts and principles involved.

Programs such as "systematic inventive thinking" (SIT), based on analyzing many patents, illustrate the interplay between structuring and problematizing in promoting creativity when solving ill-defined problems such as design projects. In such programs learners study methods for functional analysis of systems and systematic problem-solving strategies for carrying out divergent and convergent thinking.

Part and parcel in the design of instruction is the careful choice of assessment tasks and methods of scoring that align with the learning goals. These choices have a strong impact on the problem-solving practices that will take place in the classroom.

Cross-References

- ▶ Authentic Science
- ▶ Cognitive Demand
- ▶ Competence in Science
- ▶ Conceptual Change in Learning
- ▶ Information Processing and the Learning of Science
- ▶ Inquiry, Learning Through
- ▶ Prior Knowledge
- ▶ Problem Solving in Science, Assessment of the Ability to
- ▶ Problem-Based Learning (PBL)

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Problem Solving in Science, Assessment of the Ability to

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Keywords

Collaboration; Communication; Context; Formative

Assessment for Problem Solving

Problem solving is positioned as a central objective within the curricula of many countries where it is seen as providing a basis for future learning, for active participation in society, and for undertaking activities of personal interest (NRC 2010). Problem solving was introduced as an additional assessment domain in PISA 2003 because participating countries were interested to know if and how students' capacities in reading mathematics and science were matched with an overall capacity to solve problems in real-life situations. The OCED framing (OECD 2012) for problem solving links it with transfer/translation – the ability to apply what has been learned in one context to new situations. Assessment of problem solving therefore is linked to monitoring student understanding of science ideas and practices in and through tasks that have meaning and applicability beyond school-based academic success, a goal that is evident in science curricula worldwide. This contribution scopes out the nature of and challenges inherent in assessment of problem solving for formative, summative, and monitoring purposes.

Scoping the Foci for Assessment of Problem Solving

A task becomes a problem for an individual or group when they do not immediately have the knowledge and skills needed to address it. Non-routine problems require both student knowledge generation and sustained attention. A problem has meaning within science curriculum, instruction, and assessment when it provides a frame for and demands the use or development of scientific concepts, scientific disciplinary practices, and science evidentiary bases and when it is compelling and consequential for students. The PISA 2012 generic definition of problem-solving competency overviews this generally accepted meaning for "problem" and "problem solving" as follows:

> Problem-solving competency is an individual's capacity to engage in cognitive processing to understand and resolve problem situations where a method of solution is not immediately obvious. It includes the willingness to engage with such situations in order to achieve one's potential as a constructive and reflective citizen. (OECD 2010)

Assessment of student problem-solving capacity therefore needs to present students with a specific practical, real, or hypothetical problem or set of problems to solve, and it needs to take account of the breadth of conceptual, practice, motivational, and affective aspects needed to solve a problem.

While there is considerable variation in the specification of the exact capacities required in problem solving, there is general agreement that it involves, in one form or another, the following aspects:

- Recognizing that a problem situation exists and establishing an understanding of the nature of the situation
- Planning/devising and carrying out activities targeted to reaching a solution
- Monitoring and evaluating/reflecting on progress throughout the activity
- Communicating the problem solution

Students can develop and exercise these capacities through a range of pedagogical approaches, including inquiry- and project-based learning. Nonetheless, how to assess the full ensemble of the interdependent and often contingent and emergent knowledge, skills, and dispositions that students need to deploy over the course of solving an authentic problem is challenging, with this challenge present irrespective of whether the purpose for the assessment is formative or summative for students or for school, national, or international monitoring (Harlen 1999).

Challenges, Imperatives, and Opportunities in Assessment Problem Solving

The Influence of the Problem Context

Student demonstration of problem-solving capacity and inclination is strongly influenced by the context, content, and format of an assessment task. Context can relate to the everyday setting in which a problem is embedded. For instance, one subgroup of students might bring strongly held cultural values and knowledge to questions about environmental protection and sustainability, while another subgroup might bring an influential set of experiences about force and motion grounded in, say, skateboarding or basketball. The context for an assessment also includes where students undertake the task since a classroom and laboratory setting may signal different kinds of thinking that are required. It also offers different materials and resources for data generation and hypothesis testing, particularly for primary-aged students in countries where science is taught by a generalist rather than a specialist science teacher. Context can also link to students' proficiency in the language of the task and the language of science associated with the task and underpinning concepts. It can relate to the social arrangements for a task. This said, the extent to which the assessment context, rather than conceptual demand, dominates as opposed to having a modifying effect is a matter of contention, with the debate broadly linked to the extent that scholars conceive of learning as situated. Nonetheless, there is general agreement it is not valid to assess problem-solving skills via tasks that require conceptual understandings beyond those that can reasonably be expected of student respondents. While this cannot ever be completely assured, approaches for dealing with this problem depend on whether the assessment purpose is predominately diagnostic, formative, or summative or for school and system monitoring.

The context of an assessment has equity and social implications for each of these purposes and associated stakeholders. The literature indicates that an individual's degree of expertise in a given problem-solving domain has a greater influence on their approaches to problem solving within that domain than the individual's age or general developmental level. Students who perform well in one assessment item will not necessarily do so in another assessment task that targets the same skills but in a different context. On the whole, students demonstrate more advanced levels of problem solving if they have some degree of expertise or concrete prior knowledge about the task in question. Relevant, student prior knowledge and expertise can come from home or community experiences as well as from prior schooling which shape opportunity to learn and to demonstrate what one knows/has learned. It is noteworthy that the tasks in the PISA science assessment aim to take the influence of context into account through the use of topics that most students would have informal experience of in their homes and communities, irrespective of their countries. Within the problem-solving strand, the goal is that, as much as possible, tasks avoid the need for expert prior knowledge.

Assessment of Individual or Collaborative Problem-Solving Capacity

An Individual's problem-solving actions are thought to provide insight into their capabilities and inclinations to engage in and employ "higher-order" or "complex" thinking and other general cognitive approaches to challenges they might confront in life. This is especially the case when computer-/web-based assessments are used to track the resources students access and the conjectures they explore. However, the capacity to solve problems as a member of a group is recognized as essential in successful future employment and participation in twenty-first-century society. It is also central to the way most scientists work. Collaboration and communication are central the skills and competencies in current curriculum statements worldwide, including those aspects that focus on student science learning. The type of ill-defined and authentic science inquiries and projects most likely to engage students in learning and using science concepts and scientific practices and ways of communicating and consequently to demonstrate their capacity to learn, learn about and use science, generally relys on a breadth of expertise that can only be marshaled and deployed by a team.

There are significant challenges associated with assessing student collaborative problem-solving skills. These challenges are both conceptual and practical, with these two factors often intersecting such as in, for example, the issue of how do we/do we gauge individual contributions to the whole. Group final products are sometimes used as a basis for assessment, but these are not able to reflect individual or group actions, knowledge, or strategy use and development nor communication processes. Other approaches include the use of portfolios, especially e-portfolios with students encouraged to document and reflect on their actions, thinking, and decisions through the use of a range of modes and media such as digital video, audio and photographs of investigations, data collection, and so on.

The Role of Computer-/Web-Based Assessments

A number of research groups, mainly within the United States, are exploring the merits of web-based units that incorporate opportunities for self, peer, and teacher formative assessment interactions as well as the ongoing generation and collection of data that can be used to make a summative/cumulating judgment about student learning (Behrens et al. 2010). For instance, the Technology-Enhanced Learning in Science (TELS) Center has developed interactive lessons that guide students in research-based knowledge integration practices using an online map and embedded assessments. Inquiry maps guide students to articulate their ideas, test their predictions, critique each other's views, and distinguish new and elicited ideas. TELS assessments comprise multiple-choice and explanation items which ask students to connect ideas into arguments. Another example comes from the Interactive Multi-Media Exercises (IMMEX). This program tracks students' actions and data-mining strategies to arrive at a solution, grouping the strategies into types and identifying pathways into specific strategy types. In addition, it offers the possibility for students to collaborate to solve a problem and so has the potential to be used to elicit students' communication skills along with the capacity to consider other view points and self-management (Cooper et al. 2008).

PISA 2015 (OECD 2013) plans to use computer-based assessment of student collaborative problem solving. The PISA 2015 Draft Collaborative Problem Solving Framework proposes three core collaborative problem-solving competencies: establishing and maintaining shared understandings, taking appropriate action to solve problems, and establishing and maintaining team organization. The assessments will be computer based as a way of controlling the input and influence of a student's "collaborator" and to allow for the tracing of student decisions and actions. This will be the first time that "interactive problems" have been included in a large-scale international survey, and developments have implications for national and more local systems of dynamic/performance assessment.

Formative Assessment During Problem Solving

- The focus of the earlier sections has been towards the summative and monitoring aspects of assessment. Teacher and student ongoing assessment of student achievements, progress, and needs is central to teaching and learning problem solving. In order to present students with problem-based tasks, teachers need to know what might constitute a problem for their students. Units of work need to begin with an assessment of this with problems and lessons planned using this information. Subsequently, teacher and student formative assessment (Black and Wiliam 1998) is crucial for students to progress towards the successful and efficient resolution of a problem.

- Teachers need to engage in formative assessment to know where students are in their thinking and development and to assist them in deciding on next steps. Teachers can use of variety of sources of in situ information to build up a picture of student development and progress towards a potential problem solution including noting in what contexts students can perform particular tasks, what resources they access and use and how, and so on. Teachers can use resources in the setting to provide feedback to students on their progress and next steps. There is ample evidence, from a range of research programs and countries, that this is the most challenging aspect of formative assessment for teachers. This is all the more so as teachers aim to guide student problem solving when different students might pose and pursue different questions and pathways towards the resolution of the same problem. Active engagement in assessment can help in this. Student formative self-assessment is essential if students are to monitor and make informed decisions about the direction of their inquiry and in deciding on productive next actions. While collaborative problem solving distributes the load and increases access to ideas the assessment demands are increased: students need to monitor the extent to which understanding of a problem and productive solution processes is shared around the group and any actions contribute to the whole. These aspects need to be a focus for teaching and assessment.

Conclusions

Student capacity in problem solving of science-based/science-related tasks, including their capacity for collaborative problem solving, is central to their ability to participate as citizens. Student problem solving is embedded in a number of recommended instructional practices such as inquiry- and project-based learning. Assessment validates and makes visible what is deemed worthwhile, and so it is important that this capacity is assessed, both formatively and summatively. An increasing number of tools are available for teachers, schools, and other organizations to undertake this assessment, but this area remains a key focus for theoretical, practical, and policy development.

Cross-References

▶ Assessment: An Overview
▶ Formative Assessment
▶ Problem Solving in Science Learning

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Problem-Based Learning (PBL)

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Keywords

Deep learning; Group work; Solving problems

Problem-based learning (PBL) represented a major and widespread change in educational practice within higher education when introduced into McMaster University and Case Western Reserve Medical Schools during the 1960s (Barrows 2007). The teaching and learning strategy spread during the 1970s into medical schools in Newcastle (Australia), Maastricht (Netherlands), and New Mexico Universities. Since then problem-based learning has spread across the world and is currently practiced intermittently across the United States, Canada, Europe, Singapore, and Australia. From beginnings in medical schools, problem-based learning has been introduced into all of the health sciences, engineering, business, science, and education. Increasing uptake of problem-based learning (which differs from problem solving) occurred because it was considered a means to engage students in deep rather than surface learning and was viewed as a successful strategy to align university courses with the real-life professional work students were expected to undertake on graduation.

Problem-based learning is considered "problem-first learning" because it is the problem which defines the learning. Instructors design problems to represent authentic, real-world situations or issues likely to be addressed in the work place on graduation. Typically, students in small groups work through the problem to decide on the information and skills they will need to investigate the issues identified and strive to resolve the situation. Often the problem involves collaboration between disciplines so that students are required to build on current knowledge to synthesize then integrate new information. Instructors monitor group processes and facilitate student learning.

However, students themselves are responsible for the learning that occurs within the group. Generally standard problems developed in education programs are well constructed so that all elements of the problem are clear from the outset and there is a preferred process to arrive at the correct conclusion. In a shift from this format, problems crafted for problem-based learning are ill structured and vague, where students define the elements of the problem and there are often alternative pathways to alternative solutions. Throughout this student-centered and self-directed process, students collaborate to share their knowledge and reflect on their learning and assessment (Azer 2008). Contemporary examples of ill-constructed problems suitable for problem-based learning include those centered on policy (fixing a price on carbon emissions), engineering design (processing gas onshore or offshore), and ethical dilemmas (levels of support to refugees).

On beginning a problem-based learning task, students work in small groups of four to eight, which may be self-selected or allocated by the facilitator. Students often underestimate the importance of negotiating group protocols so this is the initial priority before identifying the learning outcomes and sharing their prior knowledge. They are then able to determine gaps in their collective knowledge and plan strategies to obtain further information they perceive as required. Regular group conversations occur, and during the process students commonly reassess the requirements of the task as their collective knowledge increases so that their learning focus may alter. Throughout problem-based learning, facilitators participate to support student learning without directing or providing all of the information for the students. On completion of the task, students provide a summary of their learning for assessment. This may take the form of oral presentations, formal reports, or executive summaries. It is appropriate also to include an element of peer assessment.

Modern insights on learning emphasize four elements of learning: that learning should be constructive, self-directed, collaborative, and contextual. The problem-based learning strategy meets each of these criteria. Researchers supporting problem-based learning describe many benefits gained by engaging in the strategy. The first of these is to increase students' own engagement in learning with them experiencing deep learning rather than surface learning. This is due to the alignment of teaching and learning activities and between curricular objectives and the assessment tasks. Students are also perceived as taking greater responsibility for their own learning by deciding on the information and skills they require to investigate problems and then synthesizing new information to provide solutions to those problems. While high-achieving students are often hesitant to welcome group work, many warm to problem-based learning after experiencing the student-centered focus and the opportunities to pursue group interests. Small group work also contributes to reducing student dropout because it encourages them to share and elaborate their prior knowledge, share responsibility for group goals, and engage in learning in a social context.

As a teaching and learning strategy characterized by flexibility and diversity, it is implemented in a variety of ways in different disciplines in diverse contexts. (Savin-Baden 2003; Savin-Baden and Howell Major 2004) Typically medical courses use problem-based learning case studies where a multifaceted problem is posed in place of a series of traditional lectures on sequential topics throughout a learning program. Clinical courses are often restructured and the entire curriculum remapped for the problem-based learning approach. (Barrows 2007) Engineering students are frequently exposed to problem-based learning in the form of project work during their final years of study, and science students are regularly introduced to problem-based learning to complete assessment tasks within their studies. In addition a simplified version of problem-based learning has been introduced into primary and secondary school settings in recent years, although in these contexts a fundamental aspect of much tertiary PBL is changed. In school contexts there are no forms of professional/work contexts that have the same shared immediacy for students as is the case in most tertiary contexts.

Cross-References

- ▶ Authentic Assessment
- ▶ Authentic Science
- ▶ Communities of Practice
- ▶ Cooperative Learning
- ▶ Problem Solving in Science Learning

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Process Science

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"Process science" (or a "process approach") refers to science courses or programs that emphasize the development of students' "science process skills," that is, their ability to use the "processes of science" in carrying out tasks. These are considered to be the processes which scientists follow when exploring the natural world and developing scientific explanations. There is not complete agreement among science educators on what the specific processes of science are. Most lists of processes however include observing, measuring, classifying, inferring, predicting, hypothesizing, and finding patterns, and some also add: experimenting, planning investigations, controlling variables, communicating, and others. A "process approach" to science contrasts with the more usual "content approach," in which the development of students' practical and inquiry skills is seen as secondary to, or a by-product of, the development of their scientific knowledge and understanding.

Perhaps the best-known course of this kind, and one of the earliest, is *Science – A Process Approach* (*SAPA*), developed by the American Association for the Advancement of Science in the 1960s for use in primary (or elementary) schools (Livermore 1964). The teaching activities are grouped according to the science process involved, and the course is given coherence by these rather than the science content. *Warwick Process Science*, developed for use in secondary schools in the UK in the 1980s (Screen 1986), consisted of a series of units, each designed to develop a specific process skill through activities linked only by the process involved and drawing on a range of science content.

The process approach emphasizes science as a form of inquiry, rather than as a body of knowledge. Advocates of a process approach argue that learning of process skills is more durable than learning of content and that these skills are transferrable to everyday situations and hence are a more valuable outcome of school science. A process approach is also said to enable students of a wide range of abilities to experience success in learning science. Another argument for a process approach in primary school science is that it is claimed to develop abilities that enable students to learn science content more easily and effectively in later years.

Process science courses have not, in general, achieved the impact, or levels of adoption, that their developers had hoped. The process approach has, however, influenced science curriculum design and teachers' thinking, especially at primary school level where an emphasis on inquiry rather than on content can seem more attractive and appropriate. A process approach offers a relatively flexible way of teaching scientific inquiry, avoiding a more algorithmic view of science method.

The process approach has however been quite severely criticized, on several grounds (see, e.g., Millar and Driver 1987). Its critics argue that it presents a view of scientific inquiry which undervalues the role of ideas and theories and does not distinguish science from other forms of systematic inquiry. It is also argued that children develop competence in many of the "process skills" without any specific instruction and that increasing expertise in the exercise of these skills cannot be clearly described in domain-general terms.

Cross-References

- ▶ Curriculum Movements in Science Education
- ▶ Inquiry, As a Curriculum Strand

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Proficiency Levels

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Keywords

PISA; Proficiency levels

Proficiency levels represent performance levels encapsulating typical students' proficiency in a definite interval of the scale delineated by cut points; they are characterized by ranges of values on the continuous scale grouped together into bands. These levels make possible the comparisons of performances across subgroups and of average performances among groups of students. Being at a level means that students placed at a particular level based on ability estimate would be more likely to accomplish tasks at that level. By implication, they would most likely be able to successfully complete tasks at or below that location, but would be less likely to be able to complete tasks above that point, on the scale.

For example, for print reading in Programme for International Student Assessment 2000, student scores were transformed to the PISA scale. The continuum of increasing print reading literacy is divided into five bands – level 1, level 2, level 3, level 4, and level 5 – each of equal width having two unbounded regions, one at each end of the continuum. The information about the items in each band – difficulty estimates, framework classifications in terms of text, aspect and situation, and brief qualitative descriptions capturing the most important cognitive demands – is used to develop summary descriptions of the kinds of literacy associated with different levels of proficiency. The students' locations on those scales are estimated, and the location estimates are then aggregated to generate and report useful information about the literacy levels of the respondents.

Cross-References

▶ Assessment Framework
▶ Cut Scores
▶ Scale Scores

Program

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Keywords

Plans for learning science; Science activities

Program, as used in science education, can be used to simultaneously define plans for learning science and activities that are ancillary to, and supportive of, that learning. This concurrent meaning is seen in documents such as the National Science Education Standards (National Research Council 1996). This document sets out parameters for the goals, design, development, selection, and adaptation of opportunities for learning science and establishes standards for the content, teaching, and assessment of those opportunities, taking into account the context and policies of the jurisdiction. Drawing from this document, a comprehensive science program should:

- Be developed within and across grade levels to meet a clearly stated set of goals
- Be developmentally appropriate, interesting, and relevant to students' lives, emphasize student understanding through inquiry, and be connected with other school subjects
- Be coordinated with mathematics teaching and learning to enhance student use and understanding of mathematics in the study of science and to improve student understanding of mathematics
- Give students access to appropriate and sufficient resources, including quality teachers, time, materials and equipment, adequate and safe space, and the community
- Ensure that all students have equitable access to opportunities to achieve their potential
- Empower schools to work as communities that encourage, support, and sustain teachers as they implement effective science teaching and learning

Cross-References

▶ Curriculum Structure

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Program Evaluation

► Curriculum Evaluation

Programme for International Student Assessment (PISA)

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The assessment of the science component of the OECD's PISA project introduced a radically new intention for the assessment of science learning and operationalized this with a novel instrument that included item types that had not previously been used in such large-scale testing, either nationally or internationally.

The OECD's commission for the PISA project in 1998 was to provide information to participating countries about how well prepared their 15-year-old students were for twentieth-first-century life in the domains of reading, mathematics, and science – an unusually prospective brief for the assessment of learning. Fifteen-year-old students were chosen because, in a number of countries, it is the age when compulsory study of science and mathematics can cease.

This commission required PISA Science to be not another retrospective assessment of students' science learning, as is customary at the levels of classroom, school, regional, national, and international assessments (like those used by the IEA in its ongoing TIMSS project). Such testing is closely tied to the intended curriculum for science and can be used to indicate a student's readiness to progress to the next level of schooling or to further study of the sciences beyond schooling in universities or other tertiary institutions.

Future preparedness for life in society as an assessment intention was quite unknown in 1998 among the OECD countries. There were, thus, no existing models for such testing, and one had to be developed that would lead to measures of the students' capability to apply their science knowledge to twenty-first-century contexts involving science and technology (S&T).

This innovative intention to measure preparedness was applauded and endorsed by the member countries of the OECD, but there was widespread skepticism about what would be found by such a study, since the application of science knowledge in unfamiliar contexts was not something that existing science education in schools was emphasizing. It was encouraging that the students in many countries performed well on the tests although there was clear scope for improvement in all cases.

Future Preparedness as a Goal for Science Learning

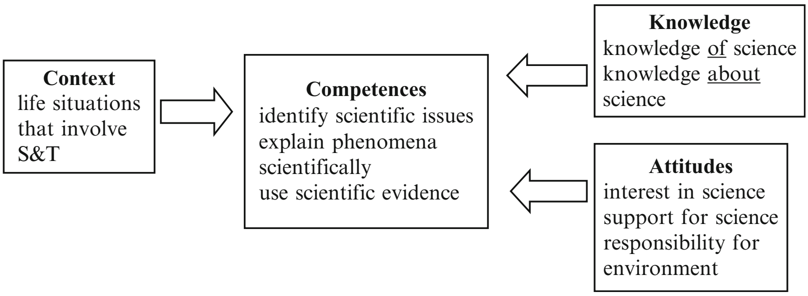
It is quite common to find the science content knowledge for teaching and learning listed in a curriculum's statement under a dual heading of "Knowledge and Understanding." It is as if these two words are synonymous, since there is usually no explanation that they may be intended to refer to different learning of the same content from shallow recall to deeper application.

This difference was made explicit in PISA Science. It would primarily measure how well students can apply the science knowledge they have learnt to novel S&T real world contexts. Hence, the PISA testing would go beyond the simple recall and application of science as it is taught and presented in textbooks.

The organization of PISA meant that science was a minor domain in PISA 2000 and 2003, so that the Science Expert Group had the opportunity to explore several approaches to its task before settling on a framework that would deliver a defined goal for student achievement in 2006 when science was the major domain. The framework is presented in Fig. 1.

The goal was a measure of students' scientific literacy defined as an individual's:

Programme for International Student Assessment (PISA), Fig. 1 Framework for PISA Science 2006 (From OECD 2007)



- Scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues
- Understanding of the characteristic features of science as a form of human knowledge and inquiry
- Awareness of how technology shapes our material, intellectual, and cultural environments
- Willingness to engage in science-related issues and with science as a reflective citizen (OECD 2006)

With this definition, PISA Science was firmly committed to what Roberts (2007) was to describe as a Vision II approach to science knowledge, which is one that looks outward to science and technology (S&T) in the everyday real world rather than inward to the sciences as specialized disciplines (Vision I).

The scientific literacy definition was differentiated as three cognitive and three affective scientific competences – *identifying scientific issues*, *explaining phenomena scientifically*, *and using scientific evidence* and *interest in science*, *support for science*, *and responsibility toward resources and environments*. The more specifically described competences were then the guides for the design of test units consisting of an S&T context about which several items could be asked relating to these competences. A fuller description of this use of science contexts in assessment and some of its shortcomings are discussed in Bybee et al. (2009).

The Mode of Assessment

The use by PISA Science of a paper-and-pencil mode of assessment has both positive and negative outcomes for science education. This mode made the testings, in general, a familiar activity to many (but not all) of the countries' students. Since PISA Science was not bound by a curriculum sense of science, PISA could use fewer simple multiple choice items and hence more valid types of item, complex multiple choice, and free response. The inclusion of the range of item, types in the projects should encourage countries and their schools to also use a wider range of assessment items since the more precise and open ones can then offer diagnostic as well as formative indications of student learning.

The development of the achievement tests for PISA Science (and for TIMSS) has involved procedures to ensure validity and reliability that go beyond those used in most countries. They include extensive face validity of the items among panels of experts, linguistic and cultural analyses for bias, and statistical analysis of extensive trials with student samples in several countries to establish each item's discriminating power, etc. (for PISA see McCrae 2009). These thorough approaches to test development now stand as exemplary models for the development of similarly intended assessment instruments at a national, regional, or local level of education, where extra-school tests and even fewer of the intra-school tests set by science teachers have such good item design.

Difficulty Level of Items

Retrospectively, the very large number of responses to its items enabled six levels of difficulty to be identified. The cognitive demand in the items of each of these levels was then described leading to quite new understanding of this feature of science learning that provides an indication of these depth dimensions for science learning, which can have diagnostic usefulness for teachers when teaching an associated topic (OECD 2007).

Assessment of Affect About Science

In the years since PISA has begun, there has been an accelerating stream of reports from international and national studies that indicate a decline in student interest in science and in science careers, particularly across the more developed countries. As in its approach to cognitive science learning, PISA Science broke new ground in associating interest in science, support for science, and responsibility for the environment, to the specifics of the science content and context as well as with a more generic measure of the first two. Thus, affective items were embedded in the contextual units as well as being asked in the student questionnaire.

The embedding of affective along with cognitive items in the main assessment test was a major innovation and contribution to science education in two ways. Firstly, it signaled very clearly that both types of learning were natural expectations from compulsory school science. Secondly, the embedding meant that students could respond positively to the specific science in one contextual unit and negatively to what underlay another contextual unit. A much richer portrayal of their affect resulted. This approach to affective responses to science is discussed in more detail by Olsen et al. (2011).

A negative aspect of PISA Science lay in its use of the paper-and-pencil mode, since there are now a number of commonly agreed curriculum goals for school science education that are not amenable to this mode of testing. The classic and abiding example of these is the assessment of practical performance in science, but now decision making about socio-scientific issues, context-based science, and science project work in and outside school can be added as not amenable to this mode of testing (see Fensham and Rennie 2013). The silence of the OECD and PISA Science on this point may unfortunately be interpreted as suggesting these other science learnings are not of worth.

Another unfortunate practice in these large-scale projects is that they release only a small fraction of the items from any one testing so that their elegance as scales is never publicly evident. By now however, enough items have been released for them to be used as reliable "item banks" for the types of science learning that PISA Science intends.

Cross-References

- ▶ Assessment: PISA Science
- ▶ Large-Scale Assessment
- ▶ Scientific Literacy

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Progression

► Learning Progressions, Assessment of

Project for Enhancing Effective Learning (PEEL)

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Keywords

Action research; Metacognition; Pedagogical knowledge; Teacher knowledge; Teacher research; Teacher Thinking; Teachers as Researchers

Background and Overview

The Project for Enhancing Effective Learning (PEEL) is a grassroots, Australian, collaborative action-research project involving teachers and academic colleagues researching ways of stimulating and supporting metacognitive student learning. It was co-founded in 1985 by John Baird (University of Melbourne) and Ian Mitchell (Monash University). It has continued for over 25 years, involving thousands of teachers, in hundreds of schools, in several countries because it addresses issues important to many teachers.

How and Why Did It Start?

PEEL synthesized two lines of research; Mitchell had been researching, in his science classrooms, ways of getting students to retrieve and where necessary restructure their existing and often alternative conceptions and had found that real and very positive classroom change was possible. These aspects of thinking involve one type of metacognition – Mitchell's students had learned to purposefully reflect on their ideas in the light of classroom activities and discussion. Baird had been researching metacognition more broadly and his work (Baird 1986) included other aspects of thinking; he had found, for example, that students commonly did not link different lessons such as theory and practical lessons, did not seek to identify the key points in something they read, and did not reflect on the purpose of an activity – or even recognize that there would be one.

Why Were Teachers Needed as Researchers?

Baird had described metacognitive thinking, but how to achieve this was largely unknown. Further progress required a group of teachers researching and developing new practices in an action-research spiral, where what was being done evolved in the light of classroom events. Baird and Mitchell agreed to collaborate with a group of 10 teachers from the school where Mitchell taught half time. The project centered around weekly meetings where the teachers developed and reflected on changes to their classroom practice that were driven by the project's goals. Unusually for the time, the teachers and their academic colleagues shared control over all aspects of the project, including research questions and design.

Goals

The overriding goal was to develop learning that was more informed, intellectually active, and independent through enhanced metacognition – the knowledge, awareness, and control of learning; however, the group knew little about what this could look like in practice. They also expected to be researching the processes of student and teacher change. As it happened, the first 3 months were extremely difficult for hitherto unsuspected reasons associated with the complexities of student change – the group had not anticipated the existence and importance of tackling what were very narrow and strongly held student views about the roles of students and teachers in classrooms.

What Caused PEEL to Spread?

PEEL was unfunded and planned as a 2-year initiative at one school. However, at the end of that time, the teachers refused to let it end, firstly because they found the process of collaborative action research stimulating and secondly because they were valuing the changes to their classrooms. More teachers wanted to join from the original school and, from 1988, from other schools. PEEL spread to other schools in a process that was unanticipated and driven by the desire of teachers to develop ways of improving how their students approached learning. A network of schools, initially secondary, but later including primary schools, developed in the state of Victoria and later among catholic schools in NSW (states of Australia). Mitchell convened this network and, to maintain coherence, established a newsletter, PEEL SEEDS, that became the journal of the project and a database, *PEEL in Practice*.[1] that at the time of writing has over 1,500 largely teacher-authored articles that can be searched by any combination of over 300 search fields relating to learning, teaching, and classroom change. In the 1990s, PEEL spread to large numbers of schools in Denmark and Sweden; from 2005, PEEL played an important role in the founding and sustaining of a network of school-based teacher research groups in China. This shows that ideas from PEEL have been seen as relevant and important in a wide range of educational contexts.

Some Outcomes

Hundreds of Cases Describing Different Aspects of Quality Learning

PEEL teachers have provided multiple and rich descriptions of what metacognition can look in a very wide range of contexts, in virtually all subjects at all levels of schooling. In doing this they have extended our vision of what is possible in terms of quality learning. When the project began, for example, the group was not sure whether students in year 7 would be old enough to be able to discuss and reflect on their learning; it is now clear that students all the way down to grade 1 can do this and take significant responsibility for their learning. These cases and the PEEL database have been used in multiple ways in teacher education at several universities; they connect theory to practice, provide credibility to theory, allow beginning teachers to share the thinking, doubts and uncertainties of experienced teachers, and provide rich stimuli for discussion.

Classrooms Became More Enjoyable

PEEL is a teacher-driven project; it began in a low socioeconomic school that presented classroom challenges to teachers. A key reason it has continued was because teachers valued their classrooms becoming warmer, more collaborative, and less stressful. The classroom looks and sounds different; there were significant changes in classroom discourse and communication (Mitchell 2010). Students, for example, ask questions that reflect monitoring of understanding – they are more explicit about what they do and do not understand and what they need or would like to know. They frame what PEEL teachers have called thinking questions that extend what is being done and allow teachers one route to building a sense of shared intellectual control by making use of these questions to drive what is being done. A growing sense of shared intellectual control means the classroom becomes a learning community with students working more collaboratively with each other and the teacher and being more willing to take risks such as sharing and defending their views, challenging something the teacher or another student says, and tackling tasks in new, creative ways.

Learning Became More Purposeful and Effective

One important outcome of metacognition is changes in roles of and relationships between students and teachers; students make a wider range of decisions and accept that they need to take more responsibility for their learning. The students build understandings that the teacher has a learning agenda and why this is important.

Metacognition promotes deep processing with students monitoring their understanding and

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[1] (See www.peelweb.org for further details on PEEL)

thinking about what they are doing and how well they understand it. Students actively seek links between different activities and ideas, between their school and home lives, and reflect on the purposes of classroom activities and how these connect to the key ideas and skills of the topic. These debriefing discussions on why we did what we did today are important; PEEL teachers found early that their students had no experience of thinking about the purpose(s) of an activity and, consequently, what they were intended to have learned from it. This meant that many classroom activities, where students had apparently successfully done what was required, were revealed as being far less effective that had been presumed.

Teachers Substantially Expanded Their Pedagogical Repertoire

Another outcome of PEEL that has been very attractive to many is a huge increase in the teachers' knowledge of pedagogy and how to achieve classroom change. PEEL has generated both shorter-term tactical and longer-term strategic knowledge of teaching. Tactical knowledge includes the development (or adaption) of over 200 generic teaching procedures that stimulate and support different aspects of quality learning such as different forms of linking. This resource has been very useful in teacher education in several universities, exposing beginning teachers to a rich tool bag of pedagogical options. Many also provide the basis for hands on workshop activities. Tactical knowledge also includes explicating what are subtle and often tacit teacher behaviors such as those associated with initiating and sustaining a fluid discussion.

The many mutually reinforcing ways of building a sense of shared intellectual control is one form of strategic knowledge in that it is not enacted in a single lesson like a teaching procedure, but over many lessons and in multiple ways. Providing students with opportunities for different types of choices and decisions, framing a small number of big ideas for any unit, and making these a focus of reflection are other strategic aspects of practice. More generally, teachers develop a learning curriculum that runs parallel with their content curriculum. As mentioned above, one of the very early lessons in PEEL was that changing how students approached learning was a complex and challenging task that needs to be done by evolution, not revolution; this becomes part of teachers' learning agendas.

Teacher Researchers Generate Different Kinds of Knowledge that Are Needed in the Knowledge Base of Education

PEEL has shown the value of teachers acting as researchers and of teacher-academic collaboration. Important aspects of the kinds of teacher knowledge briefly summarized above are not common in the academic literature because they need teachers with long-term research agendas and structures that scaffold the articulation of what is often very tacit knowledge. The benefits flow both ways; apart from the classroom benefits just listed, PEEL continued because teachers found the process of collaborative action research to be rewarding and a highly most effective vehicle for ongoing professional learning.

Concluding Comments

Much system rhetoric about education in the twenty-first century talks about the need for students to learn how to learn and to be able to learn new ideas and skills in a rapidly changing world. PEEL provides important answers as to how this might be done; it also provides ways of addressing problems of student alienation from school classrooms. The project also raises challenges to how many systems position teachers as consumers of top-down knowledge who are expected to have little independent control of what they are trying to achieve in the classroom, but rather to be responding to system level goals and initiatives.

Cross-References

- ► Meaningful Learning
- ► Metacognition and Science Learning

- ▶ Pedagogical Knowledge
- ▶ Teacher Craft Knowledge
- ▶ Teacher Professional Development
- ▶ Teacher Research

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Project-Based Learning

- ▶ Problem-Based Learning (PBL)

Public Communication of Science and Technology

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The great developments of science and technology have given us enormous and even frightening power. Owing to the discovery of electricity, medicine, and ICT, we can live a longer life with more conveniences. At the same time, however, the products of science and technology, such as eugenics and the atomic bomb, have caused serious social problems. The issues of climate change, water shortage, disease, adequate nutrition for all, and energy consumption, which we are facing now, are global problems relating to science and technology.

Effective public communication of science and technology is critical in a world thoroughly interwoven with science and technology. On the one hand, most people consider that the public is not sufficiently informed and represented when it comes to decision making about science and technology. On the other hand, scientists worldwide are more and more willing to engage with the public about their research work. Science communication aims to increase public involvement in decisions relating to science and technology by providing more accurate scientific knowledge and information and by expanding opportunities to participate in scientific and technological activities. It also aims to increase the quality of the decision-making process for research and technological applications, which today can have far-reaching effects. In addition, it helps people to understand social and cultural contexts of scientific research and become aware the beauty of science. Science and technology communication, after all, aims to increase the creativity of individuals, communities, and societies, as well as the competence of citizens when they are facing the global issues.

Public Communication of Science and Technology (PCST) started formally in late 1980 in France, slightly after the Public Understanding of Science (PUS) movement in the United Kingdom, at a time when public disbelief in science and scientists was increasing. The PCST is similar to a context model of PUS, because it is based on the consideration that cultural and social values of each stakeholder are important and must be taken into account when science is communicated to the people. Another PUS model is the deficit model where the public, assumed to be homogeneous, is considered as deficient and misguided in its present lack of uptake and understanding of science. In contrast, PCST and the context model of PUS are more concerned about the interaction among the public, the scientists, and others who are involved in communication. PCST has gained its academic support in the appearance of the master's degree courses for science, technology, and medicine communication starting from the United Kingdom and has expanded through the journals of *Science Communication* and *Public Understanding of Science*.

The main issues of PCST are expressed in the following questions: Who is able to be a good science communicator: scientists, science journalists or writers, etc.? What is the role of a science communicator, is it either a translator or a conveyer of science? Among knowledge or information, attitude, and public support, what is the most important in science communication? Which is more effective in science communication, the deficit model or the context model? How can one measure the result and quality of science communication? What are the most suitable strategies for inducing more diverse participation of stakeholders in science communication? And is it possible to have a general theory of science communication applicable not only to developed countries but also to developing countries that have such different traditions and indigenous knowledge?

In order to enhance PCST worldwide, the International Network on Public Communication of Science and Technology (PCST Network) organizes conferences or meetings in different continents. In each conference, nearly 1,000 participants offer hundreds of papers, posters, debates, and plenary lectures. The proceedings are available in the website of the PCST Academy (www.upf.edu/pcstacademy), where documents, courses, books, and events related to PCST are also available. The PCST Network is encouraging the discussion of practices, methods, ethical issues, policies, conceptual frameworks, and economic and social concerns related to PCST, linking practitioners and researchers from different cultures and countries worldwide, in both developed and developing parts of the world, and also providing opportunities for meetings and electronic interactions. And it encompasses all of the explanation and diffusion practices of scientific and technological knowledge that take place outside official and formal education. It includes science journalists, science museum and science center staff, science theater directors, science program producers, academic researchers who study aspects of PCST, scientists who deal with the public, and public information officers for scientific institutions.

Cross-References

- ▶ Public Engagement in Science
- ▶ Public Science Literacy Measures
- ▶ Science Communication

Public Engagement in Science

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The term *public engagement* has replaced the earlier *public understanding of science* movement (PUS), mainly in response to a seminal review by the British House of Lords (2000) that examined the relationship between science and society and found it wanting. Following a series of scientific debacles in the 1990s, such as the BSE (“mad cow disease”) scare and the conflict over genetically modified organisms, public trust in science was perceived to be very low. This was a matter for concern, since funding for scientific research and the recruitment of young scientists depend upon positive public attitudes towards science in general. The House of Lords review criticized the public understanding movement for being arrogant and for assuming that a straightforward top-down dissemination of science would achieve positive outcomes.

The review was not the first to comment on the role of PUS: as far back as the early 1990s, the movement had been criticized for its lack of consideration for the public *audience* and lack of respect for public knowledge. This came to be known as the *deficit model* of the public. Nevertheless the guiding principles proposed by the Royal Society in 1985, in which five imperatives for public understanding were stated, were the most influential in driving the PUS movement for the next decade. These five principles constitute arguments for greater public knowledge and understanding. The *economic argument* links a scientifically educated public to innovation and greater prosperity. The *utilitarian argument* is closely allied; the public should be scientifically aware because of the way the community uses science. Science being all around us, we should appreciate and understand how it works. In a sense, the *democratic argument* is a subset of the utilitarian argument. The general public is often asked to make decisions about new technologies and developments that have far reaching effects, locally and globally. It is important, therefore, to have some understanding of these impacts. The *cultural argument* maintains that the best science is to be compared with high art, worth appreciating for its own sake, and educated citizens should have an appreciation of their culture. (This does, however, raise the question of the culture to which science belongs.) Finally, the *social argument* observes that it is the duty of scientists to communicate their research to the public so that the public understands how the money is spent. Reports by Bodmer and Wolfendale in the 1980s and 1990s reiterated these principles and encouraged scientists to communicate their science to a broader public to further these aims. At this time, however, the expectation was that the public would, in consequence, learn and understand more science as a public duty, an assumption that was roundly criticized in the House of Lords Report. A long-term consequence of the PUS movement has, nevertheless, been the regular administration of tests of public knowledge of scientific facts, based upon a survey conducted in 1989 by Durant, Evans, and Thomas. These tests have revealed a remarkably constant level of public knowledge (or ignorance) (Stocklmayer and Bryant 2012).

The House of Lords Report called for a rethink of the science and society relationship and emphasized that the initiative for bridging the gap rested with the world of science and the scientists, not with the public. The arguments above have adjusted accordingly. The term *public engagement* is now commonly used to describe outreach activities worldwide in which the public is invited to participate. Less commonly, the term also encompasses a process of dialogue with public stakeholders, such as consensus conferences and citizen juries, where public knowledge and opinion is both heard and valued. It is now acknowledged that the primary consideration for any successful mode of engagement must be the needs and expectations of the public. Local knowledge and indigenous knowledge are respected for their contributions to the scientific debate.

The idea of public engagement has changed the nature of research into issues and dilemmas at the interface between the public and the world of science. Instead of measurement of science learning, the real complexities of goals and contexts have necessitated cross-disciplinary frameworks and methods. Although such research had its origins well before the millennium, it was not always widely recognized; a broad acknowledgement of the importance of understanding the public is much more recent. Indeed, the notion of scientists' listening to and communicating with the public has led, on occasion, to the proposal that the PUS movement should be replaced by SUP – scientists understanding the public. The emerging discipline of science communication has a strong focus on this aspect of engagement.

Cross-References

- ▶ Citizen Science
- ▶ Public Science Literacy Measures
- ▶ Public Understanding of Science, Assessment of
- ▶ Science Communication
- ▶ Scientific Literacy

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Public Science Literacy Measures

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Keywords

Attitudes to science; Civic scientific literacy; Indicators for science; Public understanding of science; Science knowledge; Science surveys; Scientific literacy; Measures

There is a considerable interest in knowing how the public, as consumers, voters and citizens relate to science and technology. There seems to be a broad agreement that *science* (or *scientific*) *literacy* is a good thing (at least as a contrast to science *illiteracy*). In the last decades there has been a proliferation of national and international studies of science literacy, but the concept is foggy and many different dimensions are suggested. There are also many stakeholders who may have competing views about what dimensions such a concept might include. This entry will raise some of the underlying concerns and point to further reading on this very broad topic.

Definitions and Limitations

A treatment of "Public Science Literacy" (PSL) clearly overlaps with other entries like "Science Literacy," "Science for Citizenship," "Citizen Science," "Public Engagement in Science," "Public Communication of Science and Technology," and possibly others. In this entry, the term "Public Scientific Literacy" is considered to be synonymous to "Civic Scientific Literacy" and the frequently used "Public Understanding of Science."

This discussion is limited to the national and international surveys that put numbers on how the adult population relates to science and can be classified as scientifically literate. But even with this limitation, there is an obvious lack of clarity of an accepted operational definition. This has led to a plethora of different instruments and an abundance of claims and findings, often contradicting each other. This is not the place to try to provide precise definitions of the terms, but rather to argue for some care when using the terms and when reading the claims and findings.

The notion of "the public" is the least problematic. In most surveys, this is understood as the entire adult population in a country or territory, often defined as older than 15 years of age, i.e., after the age of compulsory school in most countries.

What is meant by "science literacy" is more problematic. A comprehensive conceptual overview is given by Laugksch (2000). In many languages, the term "science" is a more embracing concept than in English (e.g., Wissenschaft in German). One should therefore note that most measurements of PSL are limited to aspects of the natural sciences and not, for example, the social sciences. But aspects of technology as well as the related engineering are often included in the measures; sometimes also key notions of mathematics and statistics. The report from the National Science Board of the American National Science Foundation is published every second year and is called "Science and Engineering Indicators." Each issue has a full chapter called "Science and Technology: Public Attitudes and Understanding" (NSB 2012). These chapters provide overviews of existing national (US) and international surveys and reviews of main results as well as development over time.

Discussions about what counts as "Public Science Literacy," PSL, have clear parallels to discussions about what counts as science literacy in schools and science education. The influential OECD Programme for International Student Assessment (PISA) of 15-year-old school students has the term "science literacy" as a key concept since testing started in 2000. When science was the core subject of the PISA testing, in 2006, the science education experts made a revised framework that defined "science literacy" (OECD 2006). This framework has a comprehensive discussion of this concept, also rich with references and further reading. While the first two rounds of PISA testing (2000 and 2003) confined science literacy to "competencies" (knowledge and skills) in science, the definition in the 2006 PISA testing was "expanded by explicitly including attitudinal aspects of students' responses to issues of scientific and technological relevance" (OECD 2006, p. 25). It is noteworthy, however, that the resulting PISA score that ranks countries on a scale for science literacy does *not* include the last two dimensions. A main reason is, of course, that there is no clear relationship between the different dimensions that could justify the creation of one single construct.

Stakeholders and Interest Groups

Many groups have an interest in knowing how the public relates to science and technology, both nationally and on a wider comparative level:

The science and technology (**S&T**) **community** is dependent on public trust, confidence, and support for their continued activity for a wide range of reasons: Financial support from public as well as private sources is reliant on how the public perceives scientific research and development. The public image of science and scientists is also of importance for the recruitment of young people to S&T-related studies and careers.

Politicians and their parties have an obvious interest in knowing the attitudes, values, and priorities that the voters have on most issues, and S&T-related issues are key elements in this wider political, social, economic, and cultural context.

Science teachers, **educators**, **and other science communicators** have a professional interest in understanding the knowledge as well as the affective dimensions of how the public relates to their subjects and topics.

Researchers in the social sciences (including science education) have an interest in data that enable them to look for interesting relationships between the different dimensions of PSL (like knowledge vs. attitudes to science). They also try to analyze how different indicators relate to education level, gender, socioeconomic status, etc. They are also interested in comparative data that enable cross-cultural comparisons and data stream that allow analysis of development over time.

The above groups may have different concerns and motives for being interested in how the public relates to science, technology, research, etc., and this is also reflected in what items, constructs, and dimensions they want to include in their surveys. However, educators, the S&T community, as well as industry and national authorities also have a common and obvious concern about national economical competiveness in a high-tech and knowledge-based global market. In this perspective the public preparedness for such a global competition is a concern that is shared among many groups. (Although it is far from clear what kind of knowledge and what kind of attitudes promote such competitiveness!)

Public Science Literacy: Many Dimensions

What is it about science that the public should know? What dimensions should be included in measures of public science literacy? In the following discussion, science is used in the English sense, i.e., not including social sciences, but including aspects of technology and engineering. Mathematics and statistics are not included, although some elements of these are embedded in notions of understanding experiments, fair testing, etc.

Possible (**partly overlapping**) **dimensions to be included**:

1. **Science knowledge**. Important facts, laws and relationships, key ideas, and important theories.
2. **Methods and processes of science**. The role of observations and experiments, ideas about a fair test, controlled experiments, probability, etc.
3. **Science and nonscience**. Demarcation criteria; being able to distinguish science and scientific claims from quasi-science and pseudo-science.
4. **The nature of science and scientific knowledge**. What is scientific knowledge? How reliable and stable is it? Norms and values of science. Science as part of culture. Science and scientists, the institutions of science, and research.
5. **Information sources**, **interest**, **and involvement**. What sources of S&T information does the public use? (e.g., science centers, media, newspapers, journals, Internet) Interest in

S&T versus other fields (arts, politics, sports, etc.). Interest in more specific S&T issues (space, medicine, ICT, gene technology, nanotechnology, etc.). Participation in science-related interest or action groups (environmental, anti-nuclear campaigns, signing petitions, etc.).

6. **Attitudes to science**. Science leads to a better world? Leads to destruction and war? For welfare and progress? Trust and confidence in scientists (relative to other groups). Support for basic science and applied science, R&D? In favor of more public spending on R&D in S&T?
7. **Specific S&T-related issues**: **knowledge and attitudes**. Concrete, contemporary, and potentially controversial issues like environmental challenges, climate change, energy development, stem cell research and human cloning, teaching evolution in the schools, genetically modified food, nanotechnology, animal research, etc.

Many surveys include some or all these dimensions in their instruments, together with background data on gender, age, education level, occupation, as well as political orientation and religious affiliation. Such data, often in time series for several countries and dating back since the mid-1970s, are, of course, interesting data sources for sociological research.

Not all of the abovementioned seven dimensions are, however, usually subsumed under a combined and accepted definition of PSL. The first two dimensions (science knowledge and knowledge of basic features of scientific method) are the elements most frequently included in the definition used by many authors.

It is also an interesting finding that indicators of many of the above dimensions do not correlate, for example, high science knowledge may actually correlate negatively to some attitudes towards science. Hence, combining such dimensions into one meaningful construct does not make sense, neither conceptually nor statistically. There are, however, interesting attempts to combine elements from these dimensions into a meaningful global measure of "Scientific Culture." See Bauer et al. (2012), for an anthology that contains some 26 chapters on "How the Public Relates to Science Across the Globe" from authors from all continents.

Measurement Issues

While there are many studies that claim to measure science literacy of students in schools, for example, TIMSS, but in particular PISA, there are specific challenges when measuring such qualities for the adult population in a non-formal setting. One simply cannot put members of the public to a long and controlled written test of their knowledge and skills, but must prepare surveys where the respondents are willing to participate. The knowledge items in the surveys are most often "disguised" in the form of a quiz game. Data collection may take the form of face-to-face interviews, telephone polls, or written questionnaires distributed by mail. Most items are closed, with fixed answers, but some are also open, free response. (This, of course, complicates coding significantly.) Data collection is often done by one of the many international agencies that are specialists on opinion polls. Sample sizes are usually around 1,000 or more, often drawn by stratified sampling. An overview of such data sources is provided in the abovementioned NSB reports (e.g., NSB 2012).

A challenge for indicators of PSL (as well as for school tests) is to develop items that may be used repeatedly, over long periods of time, in order to monitor trends and changes. This implies that issues that are current, topical, or controversial have to be avoided, since their place on the public and political agenda changes over time. Jon Miller, a veteran in the development of such measurements, notes that the first US attempts to measure PSL in the late 1950s concentrated on issues like radioactive fallout, polio vaccination, fluoridation of drinking water, etc. Later, the depletion of the ozone in the atmosphere received very high attention from the early 1980s. Currently, other topics dominate the political and public agenda, like genetic engineering, embryo-based research, human cloning, GMO food, nanotechnology, etc.

Contemporary surveys, like those of Eurobarometer and similar in other parts of the world, often have a set core of (relatively) stable science and technology items "that stand the test of time" (Miller 2012), plus an extra series of questions related to topical issues on frontier science and emerging technologies, often socio-scientific issues where science knowledge, values, and ethical considerations need to be combined.

The risk when choosing traditional and well-established science knowledge items as core elements in a knowledge test is, of course, that the implicit message about the nature of science is that its results are fixed and eternal and that scientific knowledge is ready-made.

Another challenge for public (and school) surveys of science literacy is the need to have items that are global, that is, of similar relevance to respondents in all countries.

Key examples of frequently used knowledge items for international comparisons in surveys like the Eurobarometer (32 countries), US, Canada, Japan, China, Korea, Malaysia, India, New Zealand follow: (These were used in Eurobarometer 2005, all with a yes/no answer.)

The Sun goes around the Earth.
The center of the Earth is very hot.
The oxygen we breathe comes from plants.
Radioactive milk can be made safe by boiling it.
Electrons are smaller than atoms.
The continents on which we live have been moving for millions of years and will continue to move in the future.
It is the mother's genes that decide whether the baby is a boy or a girl.
The earliest humans lived at the same time as the dinosaurs.
Antibiotics kill viruses as well as bacteria.
Lasers work by focusing sound waves.
All radioactivity is man-made.
Human beings, as we know them today, developed from earlier species of animals.
It takes 1 month for the Earth to go around the Sun.

It is beyond this entry to provide details on results, but it should be noted that there are very large variations in mean scores between countries. Not surprisingly, the knowledge score is also strongly dependent on the level of education of the respondent and of the education level in each country. A general trend is also that the score has been increasing over time in most countries. Further, in most countries it is dependent on age, with the younger respondents being more knowledgeable than older. To a large extent, this is a consequence of the fact that the younger age cohorts spend more time in school than the older generations did.

Cross-References

- ▶ Public Communication of Science and Technology
- ▶ Public Engagement in Science
- ▶ Public Understanding of Science, Assessment of
- ▶ Scientific Literacy

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Public Understanding of Science

▶ Public Engagement in Science

Public Understanding of Science, Assessment of

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The public understanding of science refers to the ability of individuals to read and understand information about basic scientific constructs, including some technological constructs. The concept of public understanding of science reflects a level of knowledge that would allow an individual to read current science journalism, reports from government agencies or nongovernmental sources such as the National Academies, or to watch science television shows like the PBS show Nova. It does not refer to a level of scientific understanding sufficient to obtain employment in a scientific or engineering field.

Unlike school-based measures of student achievement in science, which tend to be curriculum driven, the public understanding of science construct reflects a more functional level of knowledge and use. This construct is often referred to as scientific literacy, and in a seminal piece, Shen (1975) suggested that there are three kinds of scientific literacy. Consumer scientific literacy refers to a level of knowledge necessary to shop for foods, medicines, household chemicals, computer equipment, and modern communication equipment. Cultural scientific literacy refers to understanding science was a way of knowing as compared to other ways of knowing. Civic scientific literacy refers to the knowledge needed by citizens to understand scientific public policy issues and to make sense of competing arguments about these issues.

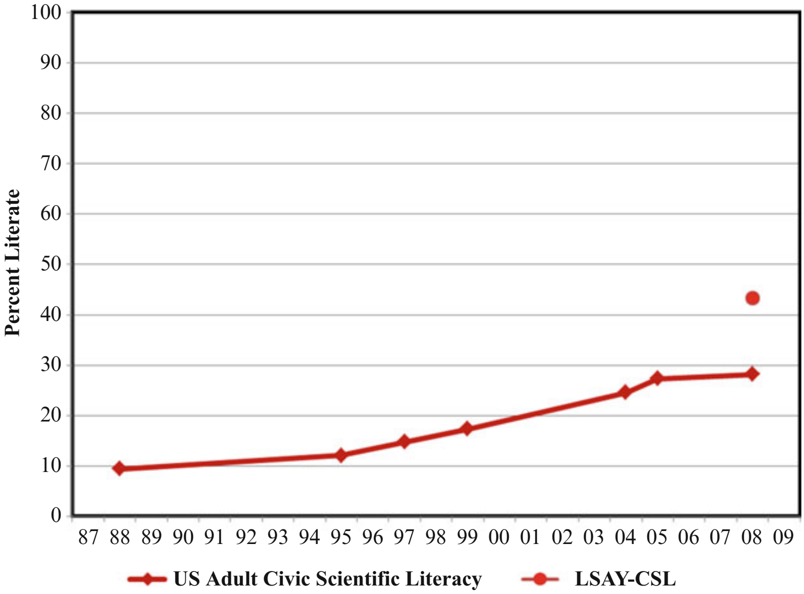
There has been some work on consumer scientific literacy, but the scope of the field is vast and most efforts at measurement and assessment in this area have been narrowed to focus on segments of consumer scientific literacy – computer literacy, health literacy, nutritional literacy, and similar slices of the range of consumer choices.

Miller and others (Miller 1983, 1987, 1995, 1998, 2000, 2001, 2004, 2010a, b, 2012a; Miller and Pardo 2000; Miller et al. 1997) focused on civic scientific literacy because of its importance to the formulation of science and technology policy and the growing importance of science and technology policy issues on public policy agendas. In broad terms, the Miller Index of Civic Scientific Literacy (CSL) reflects the ability of a citizen to read the Tuesday science section of the New York Times or an article in Science et Vie or to understand an episode of Nova. It is a minimal or threshold measure and effective democratic practice would require at least some citizens in a political system to exceed the threshold level.

Using this measure, the level of civic scientific literacy in the United States has increased from 10 % in 1988 to 29 % in 2007–2008 (see Fig. 1). A parallel study of civic scientific literacy in a national sample of young adults aged 37 to 40 – the heart of Generation X – found that 44 % of these young Americans qualified as civic scientifically literate, using the same scale (Miller 2012b). To a large extent, responsibility for this increase in civic scientific literacy rests in the uniquely American requirement that all college students complete a year of college-level science courses as a part of their liberal education. Although this result is encouraging, it is important to note that a majority of all Americans – including Generation X – still fail to meet the minimal requirements included in Miller CSL Index.

A review of comparable measures of CSL in 34 countries found that a substantial majority of adults in all 34 countries failed to qualify as scientifically literate (Miller 2012a). This result is a serious challenge to the basic premises of participatory democracy. Some critics, especially in Europe, dismiss this inability of adult citizens to make sense of important public policy issues that require some understanding of basic scientific constructs as a "deficit model" imposed by an arrogant scientific community (Wynne 1991, 1996; Ziman 1991). The argument is grounded in a belief that all knowledge – including science – is socially constructed and, as such, is politically motivated.

Public Understanding of Science, Assessment of, Fig. 1 Civic scientific literacy in the United States, 1988–2008



If scientific knowledge is socially constructed and politically motivated, then it is not necessary for every individual to know about the nature of matter or life to make judgments about science-based public policy issues. In this view, a correct ideology is sufficient.

To a large extent, this dispute revolves around whether measures of public understanding of science or scientific literacy are diagnostic or prescriptive. Miller has argued that a knowledge-based measure of scientific literacy or public understanding is a diagnostic tool to alert policy makers to a serious problem that threatens the quality of democratic discourse and participation, and there is some evidence that political leaders and policy makers follow national measures of civic scientific literacy and espouse a commitment to broaden the public understanding of science and technology. Wynne and other critics of knowledge-based measures assert that the measurement of literacy means that those adults who are not literate are illiterate and that this is an unacceptable description in a democratic society.

Cross-References

▶ Public Science Literacy Measures

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Q

Questioning for Teaching and Learning in Science

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Keywords

Asking and answering; Convergent and divergent questions; Discourse; Engagement; Locus of authority

Learning Through Questioning

Asking and answering questions about the natural world is clearly the central task of scientific inquiry. In science teaching and learning, asking students questions and encouraging students to answer questions is one of the most highly used and recognized strategies for teaching and learning. In planning science learning experiences, it is worthwhile to consider, to what extent does engaging students with questions facilitate learning about the authentic work of science? And, to what extent do questioning strategies help students learn to ask questions of their own?

In this discussion, three approaches and philosophical positions underlying learning through questioning in science are examined: (1) using questions to assess and test student knowledge, (2) using questions to gain access to student thinking, and (3) helping students learn to ask and answer their own questions in science learning communities.

- *Approach 1: In this approach, the teacher asks students questions.*

  Asking students questions is generally regarded as one of the primary tasks of the teacher. Students often learn through their experiences in formal settings that they will be asked questions about science content orally and through examinations and tests. Asking questions at the start of a lesson can usefully establish basic content information and is important in the evaluation of learning. Presenting questions for students to answer at the end of a unit is generally a key strategy used to create a record of what students know about a topic to facilitate the required creation of grade reports and information on student achievement in learning. It is helpful to consider the difference between close-ended (convergent) and open-ended (divergent) questioning strategies. Close-ended questions may be used to establish a knowledge base or in testing for content knowledge. They are questions that usually have a single correct response and can be answered only by students who know the right answer. An example is: Which planet is closest to the sun? The typical interaction with teacher and student is the following:

  - Teacher asks a question and waits for a student to answer or calls on a student to answer.

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- Student responds.
- Teacher asks another question and waits for a student to answer or calls on a student to answer.

In this approach to learning through questioning, the locus of authority and the control of the questioning interchange rest solely with the teacher. The teacher holds the correct answer, and what is valued in this exchange is obtaining the correct answer from the students. Only students who hold the correct response may participate successfully in the conversation. Questioning by the teacher is a technique for organizing learning conversations and engagement with science content and assessment. The teacher uses questions to determine whether students possess content knowledge. In this approach, the teacher asks all of the questions, knows the answers, and expects students to provide the correct responses.

- *Approach 2: Using questions to gain access to student thinking*.

Open-ended questions can be answered by any student. Open-ended questions are useful tools for uncovering the ideas students hold about phenomena so that educators may consider how these ideas interact with the content, knowledge, and skills that are designated as curriculum goals for students. Open-ended questions engage students by asking them what they observe, think, and predict or the kinds of action they suggest as useful to engage further in investigation. Some examples are as follows: What do you see happening now that the flame is lit? What do you think will happen when we add vinegar to the solution? Or, how might we investigate this topic to learn more? This approach encourages classroom conversation and discourse to learn content, and during the process of speaking and articulating their understandings, students may gain new insights. Students' correct and incorrect ideas are valued as they reveal learner understandings and help the teacher to design instruction to take into account learners' ideas. Questions are used as tools for uncovering learners' ideas and understandings about a science topic. In this approach, teachers use questions to help students articulate their ideas. Both scientifically correct ideas and incorrect ideas are valued as they give insight into the ways that students are thinking about phenomena.

- *Approach 3: Helping students learn to ask and answer their own questions in science learning communities*.

This approach to learning through questioning is based on a philosophy of learning science that emphasizes creating learning environments to help students formulate, frame, and answer questions of their own and share them in community with others. Guiding students to ask their own questions, then designing strategies to answer them, engages learners in the true discourses of science. To work in this way, teachers create environments where students are able to see that the history of science is driven by asking questions, thinking deeply about them, devising ways to answer them, and sharing the results with others. In such a setting, teachers may model the ways they ask their own questions to learn. Teachers model true science discourse by voicing questions that they do not know the answer to and encourage students to do the same. For example, a teacher may ask, "I wonder what is the best way to find out whether superworms have a preference for light or shaded areas?" The teacher models what it means to be a learner herself and encourages students to join with her to suggest ways to frame and answer questions. She creates an environment that encourages students to observe deeply, to articulate what they see, and to ask questions that emerge from their own observations, sense of wonder, and imagination. This approach makes a central place for and gives high status to learners' questions in the curriculum, and in it we see an altering of the power structure of the learning setting. Students do not wonder, "Do I have the right answer? Am I giving the answer that the teacher is looking for?" Rather, the level of discourse is elevated to conversation and questioning that is at the heart of the discourse of scientific inquiry. In this approach, it is the students who are the primary question askers. The teacher's role is to help students learn how to learn by asking their own questions, designing strategies to learn the answers, and sharing with a community of fellow learners that includes the teacher.

Cross-References

- ▶ Discourse in Science Learning
- ▶ Discussion and Science Learning
- ▶ Scaffolding Learning
- ▶ Socio-Cultural Perspectives on Learning Science

R

Radio

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The old adage that many prefer radio to television "because the pictures are better" is one which long had particular relevance to programs covering science. Whatever the topic or field – however infinitely large, infinitesimally small, or intangibly abstract – radio can be intimate, immediate, and inventive. Whereas television coverage in the past was often stymied by the struggle to stage or manufacture appropriate images and graphics, radio at its best has always been able to tap directly into the imagination and get to the heart of stories without gimmicks or distractions.

This balance has changed in recent years with advances in the quality and affordability of computer-generated imagery for TV. If anything, though, this seems to have further stimulated the public appetite for science and helped encourage not only an expansion of science via conventional radio programs but also the use of the Internet to reach audiences with an array of audio podcasts. Although these are highly variable in terms of regularity, reliability, quality, and seriousness, they are all effectively other forms of radio science.

Despite different countries having begun formal science programming at different times, there are two common threads linking much of the early output. First, there was the widely shared belief that the purpose of radio was to "educate, inform and entertain" – a phrase popularized by the BBC's first director-general John Reith in the 1920s but adopted by broadcasters around the world – and that part of that educating and informing included science. The idea that it could also be entertaining came later. Second was the simple fact that the radio itself was such a bewilderingly strange thing to have in someone's home that the first scientific challenge was to explain itself. Bertolt Brecht wrote extensively about the power of radio in the way that some leading intellectuals now write about the Internet and described this introductory phase as "a moment when the technology was advanced enough to produce the radio, and society was not yet advanced enough to accept it."

As with much radio, the format was initially dominated by scripted talks and staged interviews, often with distinct audiences in mind from children to professional organizations. In the USA, one of the first – from the early 1920s – was the *Smithsonian Radio Talks* on RCA, arranged and often given by one of the museum's more confident and clear-spoken curators Austin Hobart Clark. Clark had strong views and unorthodox views on what good science radio required: He believed all on air should be smartly attired as "the speaker who was formally dressed would make a more dignified presentation" and that any science talk "must be wholly

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accurate, dignified, and without reference to controversial points." Controversial for Clark included evolution, as according to his own theory, zoogenesis, all major life-forms evolved concurrently but separately. He also pioneered the notion of audience participation, arguing that the radio "has significant potential for gathering as well as giving out scientific information" and involving listeners in bird surveys and other data gathering.

In the UK, recordings survive of talks from such distinguished figures as Lord Rutherford in the early 1930s and of a 1942 BBC series *Science Lifts the Veil* presented by another physics Nobel laureate Sir William Henry Bragg. The archives of the Royal Society also have some revealing correspondence from immediately after the end of World War 2, as the BBC attempted to involve some leading scientists of the time (including J. B. S. Haldane, J. D. Bernal, Howard Florey, and Sir Robert Watson-Watt) in developing a new science magazine program. They were told that "the preconceptions of the BBC at this stage are almost entirely confined to broadcasting technique" and much of the discussion centered on who this program should be aimed at, with suggestions ranging from "17- to 30-year-olds of around School Certificate Standard" to "the largest professional group in the country – housewives" to "a decent agricultural labourer who has come back and is having a little rest on a Sunday." Other aspects debated included how much knowledge to assume on the part of the listeners, whether it was only acceptable to deal with areas of absolute scientific certainty (whatever they are!), and the need to show that scientists make mistakes.

All of these, along with discussions about the relative merits of programs presented by scientific experts versus those presented by science communicators, have echoes in science radio (and television) today, and there's evidence of similar issues being wrestled with by early program makers in other parts of the world. Down the decades and across the planet, science has appeared on the radio in almost every imaginable format – including phone-ins, quizzes, your questions answered, documentaries, drama-docs, soaps, and sci-fi where the "sci" bit is for once grounded in genuine science. There are also the countless, but just as important, instances where scientific discoveries, theories, and debates turn up outside of a formal "science" context, in news output, more general discussions, or other programs. In recent years it has become increasingly common to have scientific experts, authors, and presenters as guests on chat shows and elsewhere, often treated no differently from any other "celebrity" interview.

For all these experiments and innovations, the basic formulae for most science programs remain much as they were in the early days of radio: magazines, discussions, and interviews. Among the most successful are CBS radio's 15-min *Adventures in Science* which ran in the USA from 1938 until 1957; NPR's *Science Friday* slot which has now been on the air for over 20 years; BBC World Service's *Science in Action*, which having begun life as *Science & Industry* in 1959 is going strong today; All India Radio's now monthly *Vigyan Bharati*; CBC's *Quirks & Quarks* which has been on air across Canada since 1975 and for the last 20 years has been hosted by Bob McDonald; and the ABC in Australia's 1-h long *Science Show* which also began in 1975 and is still presented by its original host, Robyn Williams.

While most of these long-running series take a broad and broadly topical view of science, there are an increasing number of slots, strands, and single shows which focus on particular areas and issues within science. So on BBC radio in the UK, for instance, the main speech network Radio 4 not only has a new weekly general science magazine programme (replacing the long-running Material World), there are also recurring outlets devoted to the environment, medicine, mathematics, natural history, computing, psychology and scientific biography, as well as many one-offs and short series. In addition to this is the recent proliferation of online science programming and the Internet-enhanced ability to listen to many of these programs and podcasts at a time of the listeners' choosing, and there is now a greater access to a wider range of radio science than ever before.

Cross-References

- ▶ Broadcast Media
- ▶ Print Media
- ▶ Public Engagement in Science
- ▶ Television

Reading and Science Learning

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Keywords

Expository text; Learning theory; Metacognition; Science reading; Semiotics; Systemic functional linguistics; Text structure/genre

Introduction

This entry begins with a brief history of trends in learning theories, reading, and science education as a platform for examining science reading. The current state of science reading research is outlined, with an in-depth consideration of contemporary science reading issues emphasizing the last decade (2003–2013) of research and development activities. Then the entry summarizes this decade, including by giving an outline of research and development activities the field needs to explore. These activities are needed to enable the creation of the evidence-based science reading instruction and preparation that is required to meet the demands of the information age. This final section also gives a sketch of some promising science reading programs for elementary, middle, and secondary schools.

Reading about science was the dominant science teaching approach in almost all contexts around the globe in K–12 during the 1950s. Dissatisfaction with this approach and its failure to engage the "best and the brightest" led, at least partially, to the first-generation 1960s science education reforms and to the emphasis on inquiry and discovery approaches. A form of love–hate relationship between science education and reading oscillated between "no science until the students know how to read" and "hands-on science experiences without any reading" – this continues in various forms today.

Over the years, scientists and science educators have slowly realized that the comprehension and construction of text are integral parts of doing and learning science and that without science reading proficiency, a person is not truly scientifically literate (Alberts 2010; Yore 2012). Furthermore, correlations between science literacy and reading literacy in the 2000, 2003, 2006, and 2009 Programme for International Student Assessment (PISA), which emphasized informational text, indicated very high associations (correlations of 0.75–0.88). These are too large to be overlooked and not found for other large-scale examinations of science achievement and reading (e.g., Iowa Tests of Educational Development and the Stanford 9 Test) that stress narrative text. The PISA results suggested shared variance between science achievement and performance on reading *informational* text of 56–77 %; other test results indicated shared variance between science achievement and performance on reading *narrative* text of 10–25 %. Scientists read frequently with distinctive purposes in place prior to entering the textual world before, during, and after experimenting or observing. They read critically with pencil in hand: making notes, drawing diagrams, checking calculations, and connecting in-text ideas to their problem in the margins of the text (Yore et al. 2003). Learners need to do similar reading as they study science in formal and informal environments, but they need to "do first and read later" in order to bring something to the text since science reading is not simply a text-driven endeavor.

A brief history of science reading, and ways it was researched and conceptualized, can be obtained by tracking the patterns among models of learning, reading, and science education over

Reading and Science Learning, Table 1 Patterns in 60+ years of learning theory, reading, and science education

Time period	Learning theory	Reading	Science education	Science reading
1950s and 1960s	Behaviorism	Bottom-up	Teacher-directed dissemination of information	Vocabulary, decoding skills
1970s and 1980s	Cognitive development	Top-down	Student learning through inquiry and discovery	Cognitive strategies, building and accessing prior knowledge
1990s and 2000s	"Cold" cognition	Interactive–constructive	Learning cycles and conceptual change	Interactive comprehension and strategies
2010 and beyond	"Hot" cognition	Interactive–constructive with affective, social, and cultural considerations	Socioscientific issues, project-based learning, informal environments, and e-learning	Synthesis from multiple sources, reader interest and text relevance, integration of verbal and visual information, metacognitive strategies, and disciplinary literacy

the last 60+ years (Table 1). These patterns culminate in the current context of science reading, which suggests potential for future research and gives rise to classroom implications.

Historical Overview

Changes in science reading have been continuous, but the distinctions become obvious if the major influences are considered in 20-year intervals, as can be seen with a brief review of the past six decades. Learning theories typically influence models of reading, contribute to science education reforms, and ultimately inform ideas about science reading. The 1950s interpretations of learning centered on behaviorism – stimulus, response, and reinforcement. Authentic learning tasks were deconstructed into structured conceptual schemes, not unlike learning progressions although usually with less concern (at times even considerably less concern) with the inherent complexity of the whole that was deconstructed, and teaching was based on having learners mastering this sequence of subtasks with the help of extrinsic rewards under the assumption that the sequence would fit together to yield the original complex outcome. The 1950s view of reading was a bottom-up, text-driven process of taking meaning from text that stressed decoding skills with little consideration of the readers' prior knowledge of or interest in the focus topic. The 1950s interpretations of science instruction were teacher-directed dissemination of knowledge with an occasional primary or secondary example of the target concept, and reading about science was often the central strategy to supplement teacher talk. Textbooks were encyclopedias of lower-level science knowledge presented in genres unlike narrative (descriptive, procedural, cause–effect, etc.), with a high concentration of scientific terminology that differed from the vocabulary in developmental reading programs and varied in usage when compared to daily speech. Science reading emphasized vocabulary memorization and drill-and-practice approaches to decoding skills development. These emphases were then very commonly further reinforced by approaches to assessment.

The 1970s interpretations of learning varied worldwide, but in North America and the United Kingdom, they centered on cognitive development and learners' logico-mathematical operations and development stages. A mechanism of assimilation, dissonance, and accommodation was used to explain how people acquired knowledge or adjusted their long-term memories. However, the roles of language were not fully considered, and social transmission was rarely considered. The 1970s view of reading was a top-down, reader-driven act of bringing meaning to text that stressed readers' prior experiences, knowledge about, and intentions for the text. The 1970s interpretations of science teaching embraced hands-on discovery or inquiry approaches where teachers shared or transferred responsibilities for topic and approach to students in teacher–student-shared or student-centered approaches. In this context the reading of science materials was deemphasized or neglected totally. Many reform-based science materials of this era did not contain any supplemental reading materials for student use. Science educators argued that reading was associated with textbooks isolated from experience, and they judged such reading to be bad. Many science educators of the time implicitly shortened "textbook" to "text," leading to the generalized assumption that all texts were bad with science reading having no place in science teaching and learning. Therefore, many of the advances in reading of the 1970s and 1980s were not implemented in science classrooms.

The 1990s interpretations of learning varied somewhat internationally, but again in many countries, they centered on "cold" cognition, an analytical process of constructing understanding in working memory by combining sensory input from short-term memory with stored information and experiences from long-term memory. New understandings were then stored in long-term memory where compatible ideas were added to existing memories (conceptual growth) and incompatible ideas initiated reorganization of the memory network (conceptual change). Approaches to reading centered on an interactive–constructive process where both top-down and bottom-up features were integrated and meaning was made from text and readers' prior experiences, knowledge, and intentions in a cold and analytical fashion. The 1990s interpretations of science teaching were also influenced by cognitive psychology and ideas of conceptual change that emphasized analytical and cognitive features. Approaches to teaching science emphasized experiences with concepts throughout a learning cycle. Science reading was seen as an interactive–constructive process involving texts, contexts, and readers in a top-down/bottom-up process of meaning *making* rather than meaning *taking*. The main purpose of reading in science was to locate and share information and argue about competing interpretations of a concept.

The 2010s interpretations of learning center around "hot" cognition in which affective dimensions (motivations, emotions, beliefs, values, identities, intentions, etc.) were added to "cold" cognition where new ideas embellished preexisting representations or initiated a re-representation of prior understandings within the conceptual network. These affective factors that define humans and social cultural conditions influence people's thinking as they struggle with constraints and adapt to the demands placed on them by the learning, context, and environment. The 2010s interpretations of reading centered on an interactive–constructive framework but reintroduced affective features; they also stressed print, visual, and functional consideration of text in disciplinary contexts for making meaning. Contemporary science teaching approaches emphasize the affective dimensions of learning (e.g., attitudes, motivation, self-concept, identity) and emphasize citizenship and participation in socioscientific debate.

Science Reading Today and Beyond

The views of science reading today involve explicit consideration of current reading comprehension principles applied to scientific text – linguistic knowledge, content knowledge, general and specific reading strategies, and metacognition. When the proliferation of information communication technologies (ICTs) is taken into account and ontological and epistemological aspects of science are acknowledged in disciplinary literacy perspectives, science reading becomes an exciting, challenging, dynamic endeavor. Current trends in science reading include synthesis from multiple sources, reader interest and text relevance, integration of verbal and visual information, metacognitive strategies, and disciplinary literacy. Science reading is seen as a form of critical inquiry during which the reader constructs meaning by synthesizing ideas from multiple information sources that contain an array of different genres and modalities while assessing one's comprehension as well as the trustworthiness of sources. Not all of the information required for successful comprehension is contained in printed text. Science reading requires accessing the concepts portrayed in both verbal and visual components of text and interpreting those concepts according to conceptual, discourse, and domain knowledge.

Metacognition

Reading comprehension is a process of successfully constructing meaning from written text, while deep-level comprehension involves the construction of global meanings by accessing prior knowledge (including stored experiences), reading purposefully, determining importance, and synthesizing information. Successful science reading comprehension depends on a combination of the reader's domain knowledge and proficient use of generic reading skills and discipline-specific strategies. While reading skills are automatic processes (i.e., decoding), reading strategies are clusters of complementary skills and include the metacognitive techniques that successful readers apply in purposeful consideration of the act of reading and understanding. The concept of close reading – careful and analytical consideration of text and the range of word, phrase, and sentence meanings leading to deep understanding – is regaining attention in science. Close reading emphasizes metacognitive processes including accessing prior knowledge, identifying specialized vocabulary, reading purposefully, identifying important information, and monitoring for successful meaning making.

Scientific text, language, and metalanguage (the specialized terms of the science enterprise) do not align with everyday usage. Reading science expository text is not simply a transfer or application of strategies and tactics developed from reading narrative texts; rather, discipline-specific knowledge and strategic resources interact during the negotiations of tentative meanings constructed from the print, visual, structural, and symbolic features of the target text. Metacognition involves readers enacting their knowledge about science reading and regulating the science reading process in real time – thinking about their comprehension, as they are reading, to improve their reading comprehension.

Metacognition has somewhat fuzzy definitions and operational uses, but most definitions include knowledge about the cognitive task and personal control of the task as it is being performed. Some definitions refer to these two components as metacognitive awareness (self-appraisal) and executive control (self-management). Metacognitive awareness considers declarative knowledge (what), procedural knowledge (how), and conditional knowledge (why and when) about the specific task or class of tasks. Executive control considers several real-time functions (sometimes called skills) such as planning action, monitoring progress, and regulating action and effort. Science reading comprehension requires critical thinking, reflection, and metacognitive skills and strategies.

Multiple Sources

Science textbooks have long been the dominant source of science information in classrooms in many countries round the world. In these countries this single source of information is slowly being supplemented or even replaced by a variety of other science texts – trade books, scientific reports, adapted primary sources, news reports, and electronic media. Traditional science textbooks in North America were designed to align with federal/national and state/provincial science curricula in terms of topics and reading levels. Most science textbooks in these jurisdictions underwent reasonably rigorous development and verification procedures; as a result, they were taken as an authoritative source although they tended to promote a traditional (inaccurate) view of the nature of science and the science endeavor and sometimes perpetuated scientific myths and misconceptions.

Trade books are popular sources of information text available in bookstores and libraries that address a single topic or theme in greater depth than textbooks. They typically contain a table of contents, chapters, headings and subheadings, multiple representations, a glossary, and an index. Collections of trade books on science topics have been developed or selected to supplement some inquiry modules in elementary and middle schools by publishers, curriculum committees, and teachers. Trade books frequently use a mixed narrative–expository style that requires readers to apply comprehension strategies beyond those found in the developmental reading programs.

The use of original scientific reports and adapted primary reports has gained traction in secondary school and university science education. These alternatives to the traditional textbook can bring greater currency, depth, and relevance to specific topics; as well, their usage highlights the connections between problem, research question, inquiry, and argument. These varied sources have the potential to more accurately portray modern science as an evaluative body of knowledge arising from attempts to reason, describe, and explain nature and natural phenomena.

Traditional media (e.g., radio, television, newspaper) reports highlight contemporary science and technology research and scholarship. However, news reports (journalistic version reports) have shortcomings: they tend to be brief because of time–space limitations; they sensationalize issues by using provocative titles; they do not provide the data, theoretical backings, and reasoning behind the claims in their argument; and they distort the time between a discovery and its practical application. Specialist science programs and features (in radio, television, print) on the other hand sometimes avoid these shortcomings because of the greater time–space available to them.

Print and electronic reports (e.g., Wikipedia entries, web-based sources, and blogs) have increased the currency of science information but have inherent strengths and weaknesses. Like anything found on the Internet, the quantity and currency are great, but the editorial quality, accuracy, and validity of these sources are questionable and the reports are sometimes aggressively partisan in controversial science areas (e.g., anthropomorphic climate change, vaccination). Frequently, the driving effort is not to inform the reader but rather to market a product, lobby for special interests, or promote specific (and possibly not scientific) viewpoints.

The variety of science texts is also increasing as ICTs become more common in homes, schools, workplaces, and leisure environments. With ICT, rapid text production is commonplace as people text or email one another, add entries to their Facebook pages, and compose blogs, wikis, and tweets. These electronic texts are rich mixtures of words, symbols, videos, pictures, and invented signs unique to the writer and readers.

The expansion of information sources has contributed to the "Net" generation's preferences and approaches to acquiring information from texts. Clearly, the language arts – once conceptualized as reading and writing – need to be considered as a collection of constructive–interpretative pairs: writing–reading, speaking–listening, and representing–viewing.

Verbal and Visual Texts

Science texts, whether electronic or printed, consist of a mixture of words, symbols, and visual representations. Science texts are informational or expository, rather than narrative, and contain a range of specialized genres, features, and structures like layout, logical development, and argumentation. The language in science texts is a collection of everyday language, science concept labels, and the metalanguage of the scientific enterprise. Symbols include common signs, mathematical symbols and formulae, and content-specific notations. Visual representations include graphs, tables, diagrams, and pictures that serve decorational, organizational, representational, and interpretational functions. Well-written texts coordinate and reinforce ideas within the multiple modes of words, symbols, and visuals so that readers can move among these multiple representations to construct, enhance, and transform their understandings.

A shift in emphasis from written information to a combination of verbal and visual elements in conveying science concepts in science textbooks and trade books means that students must be familiar with the forms and functions of both language and images in order to proficiently construct meaning when reading in science. Explicit teaching is required so that readers can learn how to interpret the many visual representations found in science text. Additionally, the meanings conveyed in multiple representations must be synthesized with the information obtained from verbal text while the reader draws on prior knowledge and sociocultural conventions to build domain knowledge.

Disciplinary Literacy

Disciplinary literacy involves using a particular range of representational modes to construct and communicate knowledge. A combination of words and images constructs and represents science as known by scientists and shapes student understanding of science. The written language of science constructs, organizes, and negotiates science experiences; as a result, it has developed unique grammatical and textual features, such as high levels of lexical density (the amount of information contained in a text), abstraction, and technicality (the use of specialized terminology), and the frequent use of visual representations. Scientific discourse, both oral and print, (a) situates genres such as descriptions, procedures, comparisons, cause–effect, and argumentation as distinct forms with specific functions and (b) relies upon the linguistic techniques of noun compounding, nominal groupings, nominalization, and grammatical metaphors to construct, persuade, code, label, extend, and communicate scientific knowledge. Reading in science requires a high degree of disciplinary literacy as a reader negotiates among and between modes, identifies and understands linguistic techniques, and constructs meaning from a range of genres and multiple sources.

Semiotics and Systemic Functional Linguistics

Semiotic theory provides insights into the power of signs and representations found in science text to promote mental activity, helping readers to link abstract ideas and events and leading to understanding without direct or hands-on experience. Scientific texts are rich in signs that indicate objects, ideas, and events by convention and practice. Signs must have particular qualities or characteristics to be considered a sign: a material quality such as substance and shape, some connection with the object that it signifies, and someone to view the sign as a signifier. A sign requires that its producer and its reader share assumptions about the representation; therefore, the meaning of a sign is socially and culturally mediated. Meaning lies in the constructed associations that arise from signs and signified objects.

There is a range of signs relevant to reading and science learning. An *iconic* sign resembles some aspect of reality and shares similar characteristics with its object. A photograph is an iconic sign because it shows many of the features of the original object. An *indexical* sign shows or exhibits the object rather than standing for the object. A weathervane is an indexical sign because it indicates the direction of the wind but does not resemble the wind. A *symbolic* sign represents an object only because of convention or tradition and may share few, if any, of the features of the object. Arrows that indicate force or direction of motion are examples of symbolic signs. Full comprehension of science text requires readers to interpret a range of signs as well as written information.

Language – especially written language – is a powerful tool, likely people's most effective cognitive technology for constructing understandings, that is both necessary to and essential for doing and learning science, not merely a sign system used in the acquisition and communication of scientific knowledge. Systemic functional linguistics (SFL) offers a means to identify the unique features of scientific writing, pinpointing potential sources of reading difficulty and areas for explicit teaching focussed on comprehension. The key characteristics of science information text include text cohesion, authoritativeness, nominalization, lexical density, and technicality.

Text cohesion describes the connection of ideas contained in words, sentences, and paragraphs and is related to the degree of inference required for the reader to construct understanding. Authoritativeness describes the way in which information is presented; science text is typically highly authoritative, with information being presented with no room for doubt. Nominalization is when actions, procedures, conditions, conjunctions, verbs, and adverbs are converted into nouns as a way to expedite explanation, and it occurs frequently in science writing; for example, solidification is a noun that describes the process of turning from a liquid into a solid. The use of nominalization contributes to higher levels of abstraction, making science texts more difficult to comprehend. Lexical density is the ratio of content words compared to overall words. Typical science text has a high lexical density, which makes comprehension more challenging.

Technicality is the use of metalanguage, expressions, and techniques unique to a specialized field. The technicality of science text comes from vocabulary and relational processes. Science vocabulary involves a mixture of high-frequency words and terms with specific science meanings. Science texts often use the same word to indicate two different things: in one place a word might carry meaning as in daily use, and in another it conveys a specific scientific meaning. A common word like “power” might indicate personal or political strength or a specialized physics meaning relating to mechanics or electricity. Science texts also contain specialized terms (e.g., reagent, simple harmonic oscillation, and mitosis) and terms relating to the nature of the scientific enterprise (e.g., theory, model, and hypothesis), all terms with meanings that are unlikely to be encountered in everyday usage.

The relational processes in science text consist of structural patterns such as explanations, comparisons, classifications, and definitions that use conjunctions (e.g., and), disjunctions (e.g., or), implications (e.g., if, then), negation (e.g., not, nor), and equivalencies (e.g., if and only if) in specific ways. These relational processes also contribute to technicality. These require consideration of theme (first element in clause) and rheme (remaining element in clause). Typically, the theme contains an established or known idea, while the rheme is a new idea, thus moving the reader from the familiar to the unfamiliar.

Tippett (2011) proposed an expanded dual-track framework for science reading that included interwoven components of semiotics, SFL, cognitive, and metacognitive networks within the verbal and visual channels. This framework could be used to predict connections and constructive interactions between the verbal and visual channels not fully addressed by earlier frameworks or models of reading or representational comprehension. Additional networks or channels are needed to more fully represent the information sources, strategic resources, and dynamic, recursive cognitive mechanisms enacted in science reading, for example, domain knowledge about the nature of science and scientific enterprise, conceptual knowledge about the target ideas, and discourse knowledge about the traditions, conventions, practices, and functions of scientific language. Currently, it is unclear whether these knowledge resources are best conceptualized as a single central channel in long-term memory that is engaged during science reading and meaning making in working memory or if separate channels for science knowledge (nature of science, scientific enterprise, conceptual knowledge, etc.) and knowledge about scientific discourse (traditions, conventions, practices, functions, etc.) would more accurately predict and explain the processes of making sense of science texts.

Future Research and Developments

The complex nature of science reading is highlighted by the broad range of areas that are ripe for further research. These areas include:

- Expanding the visual/verbal framework of factors seen to affect science reading to include the influence of prior knowledge and domain knowledge
- Clarifying the role of visual information and multiple representations in science reading comprehension

- Examining how metacognition influences *science* reading comprehension
- Investigating the general and task-specific nature of measures of metacognition as it is conceptualized in reading research
- Exploring the mediating roles that metacognitive awareness and executive control appear to play in activating and enacting conceptual and discourse knowledge in science reading comprehension
- Investigating the convergence among metacognition, critical thinking, and reflection on science reading
- Identifying the cognitive factors that influence readers' ability to integrate information that is presented in multiple modes, to identify important information, or to ignore irrelevant information
- Gathering more evidence to validate the use of science reading strategies that are anecdotally reported as improving comprehension to establish "best" practices
- Conducting more research from a "hot" cognition perspective to investigate the impact of the relevancy of science information and the personal interest, intention, or motivation of the reader upon science reading comprehension

Such research will contribute to our understanding of science reading and the many factors that influence making meaning from and with science text.

Closing Remarks

Future research and development in science reading needs to consider both the mainstream (citizenship) and pipeline (career) demands on science literacy. There have been some promising explicit science reading comprehension programs that emphasize reading strategies, vocabulary development, and metacognitive awareness and executive control in elementary and middle schools (cf. Seeds of Science/Roots of Reading, Pearson et al. 2010; University of California Berkeley, Lawrence Hall of Science). However, there have been only limited efforts to understand and develop twenty-first-century science reading knowledge and abilities in high schools and universities (Fang et al. 2011; Fang and Pace 2013; Yore et al. 2003).

Cross-References

- ▶ Code-Switching in the Teaching and Learning of Science
- ▶ Conceptual Change in Learning
- ▶ Constructivism
- ▶ Discourse in Science Learning
- ▶ Evaluation of Textbooks: Approaches and Consequences
- ▶ Language and Learning Science
- ▶ Metacognition and Science Learning
- ▶ Multimodal Representations and Science Learning
- ▶ Sociology of Science
- ▶ Writing and Science Learning

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Relevance

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Questions surrounding the notion of relevance (e.g., relevant to whom, for what, and who decides) are central to the goals of education. However, while the questions have an enduring quality, the answers are socially, historically, and politically contingent and, in some circumstances, are governed by ideological or religious dogma. They are also subject to both internal (e.g., training the mind) and external (e.g., the supply of qualified personnel) referents and to the tensions that arise when different interpretations of relevance require different approaches to what and how science should be taught and assessed.

In the nineteenth century, as science struggled to secure a place within many school systems, relevance was commonly framed with reference to the acquisition of scientific habits of mind ("scientific method") and to the contribution that science could make to a liberal education, the latter being a key outcome commonly associated with the study of the classical languages and mathematics. A contrasting rationale, however, sought to familiarize students with the "science of common things" by emphasizing contextualized knowledge and understanding rather than more abstract scientific thinking (Layton 1973). Each rationale required different content and pedagogy, promoted initially with little or no reference to the psychology of learning. When the latter eventually became more influential in the politics and practice of education, relevance also gradually came to be seen to require matching of what and how science was taught to the maturing mind and shifting interests of the pupils.

Partly in reaction to the role that science had played in the First World War, the emphasis in the interwar years in many Anglophone education systems moved away from an exclusively disciplinary approach to school science to accommodate explicit attention to the human dimensions of scientific activity (Donnelly 2004). Teachers were urged to attend to the biographical and historical aspects of the scientific disciplines and to highlight the personal qualities of outstanding scientists. Relevance thus acquired a strongly moral dimension with scientists presented as dedicated to the pursuit of truth and as sometimes displaying heroic qualities in the face of criticism or personal difficulties. In addition, ideas about how children learn and might thus be taught exerted a greater influence on pedagogy, especially, although not exclusively, in the scientific education of younger children. Such ideas also influenced the selection of some of the scientific topics to be taught and the order in which they should be presented, the latter being determined by the relevance of individual topics to the students' ages and assumed interests. In other education systems, notably Nazi Germany, the former Soviet Union and communist China, relevance was subject to the over-riding political ideology, with school biology being particularly, although not exclusively, affected (Renneberg & Walker 1994).

In many Western education systems, the ending of the Second World War brought a shift in attention away from attempts to widen the goals of school science and led to the focusing of attention on the urgent need to increase the supply of qualified scientific personnel for both civilian and, especially during the period of the Cold War, military purposes (Rudolph 2002). It was a shift that eventually led in the 1960s to a global movement for school science curriculum reform that involved the modernization of content and the promotion of a pedagogy underpinned by the belief that students could best learn science by doing science and, in some cases, supported by Piagetian notions of cognitive development. Relevance thus owed as much to a perception of national needs as to developing the ability to think scientifically by engaging in "authentic science."

Postwar developments, however, also highlighted the social dimensions of the relevance accorded to school science. Differentiation of curricula, either between or within schools, has been a long-standing feature of science, as of most other subjects of the school curriculum in most education systems. Such differentiation reflected widely held assumptions about, for example, the roles of women in society and the intellectual ability or likely future occupations of different groups of school students. In the mid-nineteenth century, elementary and secondary education were strongly associated with different social classes within society, each of which was presumed to require a different type of scientific education and, in some cases, no such education at all worthy of the name. For much of the twentieth century, an introduction to the grammar and syntax of canonical science was judged inappropriate for those who would work in the manual sector of employment, become housewives, or take up occupations for which the knowledge and intellectual training provided by a scientific education was judged irrelevant or of marginal importance. Domestic science and the biological sciences, especially botany and, to a lesser extent, chemistry, were thus commonly judged more relevant to the future needs of girls than physics.

In the latter half of the twentieth century, these historic assumption about relevance associated with school science education were challenged by several developments, although a concern to promote scientific thinking, expressed in a variety of different ways such as "processes" and "skills," was never lost. Newly independent countries sought to give science curricula a rationale that they judged more relevant to their individual circumstances and that was sometimes strongly influenced by narrower nationalistic or religious factors. Attempts to accommodate technology (or design and technology) within school curricula focused attention on the relationship to science, and the rise of information and communication technologies raised important questions about learning and pedagogy. Feminism and other movements concerned to promote equity, the rise of environmental concerns, and the growing interaction of science, technology, and society all contributed to a reassessment of how school science could be made relevant to the needs of pupils growing up in a rapidly changing society. Such challenges were not always readily welcomed by practitioners or policymakers nor were they experienced equally within different education systems. Nonetheless, the period witnessed the introduction of several curriculum initiatives that emphasized "science in context," including the seminal science-technology-society (STS) courses and modules, all of which served to bring the issues surrounding "science for all" to the forefront of professional and political debate.

As the interaction of science, technology, and society became increasingly complex and, in many cases, contentious, the relevance of school science came to be defined with respect to scientific literacy and the public understanding of science: terms that, among much else, related to an ability to engage intelligently with the moral, ethical, economic, or other questions prompted by such interaction. The promotion of such literacy and understanding, however, had to coexist with the need to safeguard the future supply of qualified scientists and technologists, a matter of increasing concern when, during the closing decades of the twentieth century, the popularity of the physical sciences as subjects for advanced study declined in almost all industrial societies.

This decline in popularity of the sciences and the seeming irrelevance of these disciplines to the interests and aspirations of many young people prompted numerous national and international research studies. Among the latter, the Relevance of Science Education project (ROSE) generated a large volume of international data that revealed significant differences between students in the developed and developing worlds in their attitudes to science and technology. In addition, while many students in the developed world had a generally supportive view of science and technology, their attitudes to school science were much less favorable. The ROSE findings contributed to, and confirmed, those of a burgeoning volume of research that explored the "student voice" and established that students' perception of the relevance of their school science education is sensitive to age, to gender, and to cultural and linguistic diversity. The implications of this finding present formidable challenges for the relevance of science education in multicultural societies and for the notion of a science curriculum that seeks to reflect universal scientific findings (Aikenhead & Michell 2011).

A further issue for many legislatures has arisen from the results of international comparisons of student achievement in science, such as TIMSS and PISA, which focused attention on the strengths and weaknesses of different school systems. In many of those systems, the outcomes of such comparisons have led to a revaluation of the relevance of school science education to such goals as problem solving and scientific literacy.

Legitimate interests in the relevance of school science are many and diverse: they range from policy makers, legislators, and teachers to scientists, curriculum developers, and students. Given this, the long-standing and enduring search for such relevance is inevitably a series of compromises that reflects wider changes in society, in politics, and in the professions most closely concerned with science and education.

Cross-References

- ▶ Authentic Science
- ▶ Curriculum Movements in Science Education
- ▶ Interests in Science
- ▶ Transposition Didactique

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Religious Education and Science Education

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Introduction

Worldwide, religion is of importance to many people. While many people with a religious faith are entirely comfortable with how scientists understand the world, others feel that aspects of science are incompatible with their religious faith. This entry discusses the nature of religion and the nature of science and then examines how religion and science might relate. The aims of religious education and science education are considered and ways of teaching science to take account of religious beliefs are examined.

The Nature of Religion

Religions vary greatly. Nevertheless, the great majority has a number of features in common (Reiss 2008). For a start they have a *practical and ritual dimension* that encompasses such elements as worship, preaching, prayer, yoga, meditation, and other approaches to stilling the self.

Then there is the *experiential and emotional dimension*. This includes the rare visions given to some of the crucial figures in a religion's history, such as that of Arjuna in the *Bhagavad Gita* and the revelation to Moses at the burning bush in *Exodus* and the experiences and emotions of many religious adherents, whether a once-in-a-lifetime discernment of the transcendent or a more frequent feeling of the presence of God either in corporate worship or in the stillness of one's heart.

All religions hand down, whether orally or in writing, vital stories that comprise the *narrative or mythic dimension*, for example, the story of the birth, life, death, resurrection, and ascension of Jesus in the Christian scriptures. For some religious adherents such stories are believed literally, for others they are understood symbolically.

The *doctrinal and philosophical dimension* arises as theologians work to integrate the narrative/mythic dimension into a more general view of the world. Thus, the early Christian church came to its understanding of the doctrine of the Trinity by combining the central claim of the Jewish religion – that there is but one God – with its understanding of the life and teaching of Jesus Christ and the working of the Holy Spirit.

The *ethical and legal dimension* regulates how believers act. So Sunni Islam has its Five Pillars, while Judaism has the Ten Commandments, and other regulations in the Torah and Buddhism its Five Precepts.

The *social and institutional dimension* of a religion relates to its corporate manifestation, for example, the Sangha (the order of monks and nuns founded by the Buddha to carry on the teaching of the Dharma) in Buddhism and the Umma' (the whole Muslim community) in Islam.

Finally, there is the *material dimension* to each religion, namely, such things as places of worship (e.g., synagogues, temples, and churches), religious artifacts (e.g., Eastern Orthodox icons and Hindu statues), and sites of special meaning (e.g., the river Ganges and Mount Fuji).

The Nature of Science

The nature of science is considered in more detail via a wide range of entries in this encyclopedia. Key points to emphasize here are that while the subject matter of science has varied considerably over the centuries, often because of advances in instrumentation, its principal approaches to building up reliable knowledge are fairly consistent. Of central importance is the objectivity of such knowledge – i.e., the knowledge should be independent of the person generating it (unlike, e.g., the work of painters, of composers and novelists, and perhaps of psychoanalysts) – and, relatedly, that such knowledge can be rigorously tested, often by experiment, though such experimentation is less direct for the historical sciences, such as much of geology and evolutionary biology, and for certain other sciences, e.g., astronomy.

How Might Science and Religion Relate?

There is a large and growing literature on how science and religion relate, but the most frequent classification remains that of Barbour (1990) who provides four categories. First, there is conflict. This is the relationship favored by some fundamentalists and by many so-called militant atheists.

Secondly, there is independence. Science and religion are seen as independent either because they use distinctive methods or because they seek to answer different questions. In any event, the result is that each is seen as distinct from the other and as enjoying its own autonomy. The relationship of independence has been favored by many, such as Stephen J. Gould, who holds that both science and religion are worthy of respect but occupy distinct spheres of human enquiry.

Thirdly, there is dialogue. As an example, Barbour points out how our understanding of astronomy has forced us to ask why the initial conditions were present that allowed the universe to evolve. The point is not that the findings of science require a religious faith. Rather, the point is that scientific advances can give rise (no claim is made that they do for all people) to religious questions, so that a dialogue ensues.

Barbour's final grouping is one in which the relationship between science and religion is seen to be one of integration. For example, in natural theology it is held that the existence of God can be deduced from aspects of nature rather than from revelation or religious experience. Natural theology has rather fallen out of favor. Its obverse is that characteristics of God can be deduced from aspects of nature, since the created order is held inevitably to reflect something of its author and sustainer.

The Aims of Religious Education and Science Education

There was a time when the principal aim of religious education was to convert learners to a particular religion or, more often, to keep them within that religion. In some countries this remains the case, but in liberal democracies this is no longer held to be acceptable. Instead, religious education has moved to teaching about religions, showing how people with a religious faith live their lives and understand the world. A frequent claim of those who favor this form of religious education is that, done well, this can also increase tolerance between people of different religions or none.

Science education too has shifted its aims, though in a less clear-cut manner. Unsurprisingly, the main aim of science education is to enable learners to understand how science is undertaken and to know some of the principal contributions to knowledge that it has made – such as the particulate nature of matter, the germ theory of much disease, and the structure of the universe. It remains the case that one aim of school science education is to produce the next generation of scientists, even though science educators have increasingly pointed out that only a minority of school students fall into this category. More recent aims are for school science education to enable citizens to make informed decisions, to promote democracy, to advance social justice, and to lead to socio-political action (Reiss 2007).

Ways of Teaching Science to Take Account of Religious Beliefs

If science teachers deal with religious issues, or science issues that have religious connotations, they should be true to science and respectful of their students and others, irrespective of such people's religious beliefs. Indeed, nothing pedagogically is to be gained by denigrating or ridiculing students (Jones and Reiss 2007). The aim of including religion in science learning is not primarily to teach about religion, but to enable richer and more effective ways to enable students to understand certain ideas within science and to help them understand better certain topics where science and religion interact.

The principle of respect for students has implications for assessment too. Well-designed examination material should be able to test student knowledge of science and its methods without expecting students to have to convert, or pretend that they have converted, to a materialistic set of beliefs. So, for example, while it is appropriate to ask students to explain how the standard neo-Darwinian theory of evolution attempts to account for today's biodiversity, it is inappropriate to ask students to explain how the geological sciences prove that the Earth is billions of years old.

A particular cause célèbre in the science-religion debate arises when teaching about evolution, particularly when some learners come from creationist backgrounds. Part of the purpose of school science lessons is to introduce students to the main conclusions of science – and the theory of evolution is one of science's main conclusions. For this reason, school biology and earth science lessons should present students with the scientific consensus about evolution, and parents should not have the right to withdraw their children from such lessons. At the same time, science teachers should be respectful of any students who do not accept the theory of evolution for religious (or any other) reasons.

Science teachers should not to get into theological discussions, for example, about the interpretation of scripture. They should stick to the science, and if they are fortunate enough to have one or more students who are articulate and able to present any of the various creationist arguments against the scientific evidence for evolution (e.g., that the theory of evolution contradicts the second law of thermodynamics, that radioactive dating techniques make unwarranted assumptions about the constancy of decay rates, that evolution from inorganic precursors is impossible in the same way that modern science disproved theories of spontaneous generation), they should use their contributions to get the rest of the group to think rigorously and critically about such arguments and the standard accounts of the evidence for evolution.

Cross-References

- ▶ Biology, Philosophy of
- ▶ Chemistry, Philosophy of
- ▶ Context of Discovery and Context of Justification
- ▶ Earth Science, Philosophy of
- ▶ History of Science
- ▶ Hypothetico-Deductive Method
- ▶ Social Epistemology of Science
- ▶ Social Studies Education and Science Education

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Reporting Results of Large-Scale Assessments

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Keywords

Large-scale; NAEP; ; PISA; TIMSS

Large-scale national and international assessments of science for students at elementary and secondary school levels are now conducted regularly in about 70 countries. The purpose of the assessments is to measure trends in each nation’s performance in educating children in the sciences. The statistical studies are repeated at regular intervals to provide important information for policy makers of educational practices on achievement levels for students of different backgrounds such as parent’s education, parental involvement, race, ethnicity, and language spoken. They also provide important measures of the condition of homes, schools, and teachers that affect learning such as student exposure to science content, study practices, and attitudes toward science.

The two international assessments of science that are conducted regularly are the Trends in International Mathematics and Science Study (TIMSS) which is conducted in 63 countries and managed by the International Association for the Evaluation of Education (IEA). The second study is the Program for International Student Assessment (PISA) which is conducted by the Organization for Economic Development (OECD) in about 70 countries.

The assessments contain test items based on a systematic framework of the physical sciences, life sciences, earth, and space sciences, but not of engineering or the social sciences. The test items are made up of specific questions about the content of scientific principles as well as questions that require students to solve problems such as how environmental change occurs. Each of the surveys uses a slightly different framework for defining the content of science intended for elementary and secondary school students. For example, the PISA framework determines whether students are able to solve practical problems faced by working technicians, scientists, and engineers (OECD 2009). The TIMSS assessment stresses students learning of science topics that are specifically presented in the classrooms of most science classes around the world (Mullis et al. 2003). The frameworks are revised occasionally to incorporate the results of research in the sciences and educational practices.

The results of national surveys of student performance in science are reported in publications with statistics that depict the distribution of student population scores (NCES 2011; Martin et al. 2012; OECD 2010). Rather than average the number of correct answers to test items (as would occur in Classical Test Theory), student responses are turned into a scale of science achievement using psychometric models such as Item Response Theory (IRT) that take into account the level of difficulty of each item. This approach improves the ability of the scale to distinguish differences between individual students. The assessment scales are reported within a wide range, such as from 400 to 600 (or any other range arbitrarily chosen by the test constructors) so that the results can be easily summarized into statistical averages or distributions and may be compared with tests administered in previous years to measure change over time (see references to websites). The test scores, however, should not be compared between studies (such as NAEP, TIMSS and PISA) even though they look alike because the underlying test frameworks define science ability somewhat differently.

In order to place the levels of the scale into more meaningful categories, the studies have also created ideal achievement goals called "proficiency levels" that approximate how well students should perform in science. The proficiency levels are reported as the percent of students who perform at, above, or below ideal levels of achievement. In the US national assessment, NAEP, the ideal levels of achievement were established by a national group of experts, the National Assessment Governing Board (NAGB 2008), who were authorized by Congress to standardize the interpretation of the test scores. NAGB sets ideal achievement goal levels from the science assessment score as the percentage of students who scored at or above basic, proficient, and advanced levels. "Proficient" achievement is defined as "solid academic performance exhibiting competency over challenging subject matter." Basic achievement is performance that exhibits "partial mastery over skills fundamental to Proficient performance." Advanced levels of proficiency in science is defined as a student who "demonstrates a solid understanding of the earth, physical, and life sciences as well as the ability to apply their understanding to practical situations at a level appropriate to their Grade" (Loomis and Bourque 2001). The TIMSS study similarly reports the test scores in four levels of "benchmarks" (Advanced, High, Intermediate, and Low; Martin 2012, p. 8). And, the PISA study creates six levels of "proficiencies" that range from low (limited scientific knowledge that it can only be applied to a few, familiar situations) to advanced (students level can use scientific knowledge and develop arguments in support of recommendations and decisions; OECD 2010, p. 149).

Some of the student and school characteristics that are known to affect the level of student achievement are regularly reported in all assessments such as the home environment (parent's level of education, race and ethnicity, number of books in the home, amount of study time, and level of after school activities), the school environment (the amount of resources available to teachers, level of teacher preparation, and the school climate), and the attitude of students toward the subject matter.

Cross-References

- ▶ Assessment: PISA Science
- ▶ Large-Scale Assessment
- ▶ Third International Mathematics and Science Study (TIMSS)

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Representation

► Multimodal Representations and Science Learning

Representations and Learning in Science

► Multimodal Representations and Science Learning

Representations in Science

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Science, perhaps more than any other discipline, is characterized by the use of a huge number of ways to represent its knowledge. When scientists explain and analyze phenomena in the natural world, they make use of graphs, diagrams, tables, equations, definitions, analogies, metaphors, etc., and often new findings are followed by new forms of representations. Physicists at lunch draw sketches at their napkins while orally formulating their points and making gestures with their hands. Magnetic and electrical fields are illustrated with field lines and calculated using vector operators. The quantum understanding of the atom developed the energy diagram. These are examples of why the understanding of and the ability to use different representations are crucial in the understanding of science and why they form some of the basic building blocks in the teaching and learning of science.

Within cognitive science, psychologists have for many decades struggled with how we represent the outer world inside our heads, how the representation is organized as knowledge in our memory, and how we can retrieve it in other situations. This approach to representation can most recently be traced back to Jerome Bruner and his colleagues in the book *Studies in Cognitive Growth* from 1966. They maintained the idea that human beings can represent the world in three ways: by acting, by image formation, and by constructing sign systems. This was inspired by Jean Piaget and, as a parallel with Piaget's stage theory, Bruner and his colleagues also meant that the three approaches to understanding the world formed a developmental sequence. Bruner has later changed his view on learning toward a more sociocultural understanding in which representations are seen as cultural tools, used in concrete situations for a concrete purpose. In a science education context, it is useful to combine the cognitive and sociocultural approaches to representations; representations are both practical tools developed to express the understanding of a phenomenon and at the same time a mental resource. As such representations are notions or signs or symbols that stand for something in the absence of that thing, a thing which typically is a phenomenon or an object in the external world but can be just in our imagination. This external representation is thus learned by ascribing meaning to it, i.e., by giving it an internal, mental representation that links to both the object and its external representation. In semiotic terms, the process of learning a representation becomes understanding it and giving meaning to it as a sign that signifies something about an object.

Given the central place of representations in science, the "big" questions in the context of this encyclopedia are as follows: which representations are particularly useful in science education, and why are these useful? Consider the example of electricity. In a typical lesson, students will discuss the nature of the concepts "current," "resistance," and "voltage"; they will set up an experiment using connecting wires and meters; they will draw the setup; they will log some data; they will systematize the data in columns and graphs; they will hypothesize or verify relationships; they will discuss their findings; they will need to use the proper units.

These situations all involve different forms of representation and it is not possible to give a conclusive list of all possible forms or to put them in logical coherent groups that embrace all forms without overlapping. One way of categorizing the most used representations is in the following groups:

- Phenomenological representation

  An oral or written narrative of the phenomenon you observe or are working with
- Experimental representation

  An experimental setup with material, measuring instruments, software, etc. to investigate the phenomenon
- Mathematical descriptive representation

  Graphs, tables, diagrams, etc. maybe based on logged data or from other sources
- Mathematical symbolic representation

  Functions, equations, formulas, etc. describing and linking and arranging the data
- Conceptual representation

  The definitions, concepts, generalizations, and theories that can clarify and explain the phenomenon
- Figurative representation

  Drawings, metaphors, analogies, and simulations that can visualize and connect to known understanding
- Kinesthetic representation

  Bodily actions expressing the phenomenon at hand

The concept of representation has an inherent duality: On the one hand, it is a *result*, a property, or a characteristic feature or behavior of a scientific phenomenon, and on the other hand, it is also a *practice*, something that is done in science. This duality means there is a need for two different approaches when working with representations in the science classroom. From the perspective of representation as a result, learning science can be seen as a process where students learn the different representations within the specific science domain and where the representations can contribute to a differentiated and multifaceted understanding. When considered in terms of practice, representations can be seen as a more competence-oriented approach where students' abilities to construct representations themselves are seen as a powerful path to learning. Both these approaches acknowledge the importance of having multiple representations for the same phenomenon in order to have a full understanding of that phenomenon. One single representation cannot cover all possible aspects of a topic, and multiple representations using different modes will give a more complete understanding.

It is useful to see a learning process in science as a process where the student appropriates the different representations of the topic/object/phenomenon and is able to shift between them and is able to select an appropriate representation for addressing a particular purpose. Knowledge arises in the transformations between representations, when the student uses one form of representation or the result from one representation in another representation of the same topic. The more the different representations are integrated by the student, i.e., the more transformations and links the student can establish between the representations, the deeper the student's understanding.

Relating different representations can be extremely difficult for students. Research shows that even when students have learned two different forms of representation, they primarily use one of them and only very few students understand how the two forms are connected. For example, high school students have been shown a figure of a ball rolling along a track and then asked to sketch the corresponding graphs of position versus time, velocity versus time, and acceleration versus time. Only 1 out of 118 students was able to do this correctly. At a technical university, little less than half of the undergraduate students passed their calculus-based examinations without being able to understand the fundamental concepts entering into the equations and calculations. This also illustrates the huge learning potential in working with multiple forms of representation to get a full understanding of the problem at hand.

Learning and constructing multiple representations constitutes an efficient path to deeper understanding of a topic – but it is not an easy path to walk. Letting students construct their own representations will normally lead to a better understanding than interpreting a given representation. Learners also need to be confident with one form of representation before another is introduced. The order in which representations are introduced is important. Research indicates that learning qualitative representations should precede quantitative representations. Phenomenological, figurative, and kinesthetic representations will give an organization of the topic that promotes an understanding of a more quantitative representation such as a mathematical symbolic representation. Computer-based animations simultaneously displaying multiple representations of the same simulation can provide a good learning environment for linking between representations.

Cross-References

- ▶ Models
- ▶ Multimodal Representations and Science Learning
- ▶ Scientific Visualizations
- ▶ Visualization and the Learning of Science

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Research Informed Practice in Science Education

▶ Evidence-Based Practice in Science Education

Retention of Minorities in Science

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Keywords

Higher Education Access

Minority retention in science refers to efforts of educational, government, and corporate agencies to ensure that ethnic and racial minorities as well as women are proportionately represented in the science workforce.

Efforts to improve minority retention in science are driven primarily by the condition of widespread underrepresentation of some minority groups in the science workforce. For example, in USA African Americans, Latinos, and Native Americans typically participate in the science workforce in numbers that are disproportionately smaller than their representation in the larger population. In 2008, these minority groups (frequently referred to as “underrepresented minorities”) comprised 9 % of workers in science and engineering occupations and 26 % of the general population. By contrast, Asian Americans tend to participate in the science workforce in numbers that are disproportionately greater than their representation in the larger population. In 2008, Asian Americans comprised 17 % of workers in science and engineering occupations and just 5 % of the general population (National Science Board 2012). So Asian Americans are not generally considered “underrepresented minorities” and rarely are they targeted for minority retention efforts.

Minority retention efforts are widespread and varied. They involve remediation, enrichment, informal science education experiences, and enhanced or extended formal science education experiences. Minority retention efforts target learners at virtually all age and grade levels, including early elementary-aged students ranging up to advanced graduate students. An example of a common minority retention effort is the summer bridge program. Many university science and engineering departments offer summer bridge programs to incoming freshmen from underrepresented minority groups. Summer bridge programs involve students in accelerated study of science and mathematics coursework that is designed to prepare them for the first year of college. Summer bridge programs may be aimed at either remediating incoming freshmen, giving them a head start on university level work, or some combination of the two. These abbreviated periods of intense study are also intended to help incoming freshmen acclimate to university life.

Although minority retention efforts are widely used by educational, government, and corporate agencies, there is not a strong empirical basis for the effectiveness of these efforts. Consequently, a common practice of successful minority retention efforts is that they employ many interventions simultaneously rather than rely on one or two types of interventions. This practice is sometimes referred to as “overdetermining for success.” One example of a nationally recognized minority retention effort in science that overdetermines for success is the Meyerhoff Scholars Program. This program is an effort of the University of Maryland, Baltimore County (UMBC) that is aimed at increasing the number of underrepresented minorities who pursue advanced degrees in science. Numerous studies have shown that Meyerhoff Scholars earn higher grade point averages, graduate in science at higher rates, and enter graduate school at higher rates than national comparison samples. Rather than focusing solely on one type of intervention, such as financial aid, the Meyerhoff Scholars Program employs up to 14 types of interventions, including financial assistance, enhanced recruitment efforts, a summer bridge program for incoming scholars, formation of study groups, establishment of a culture of success through program values, establishment of a culture of support through program community, personal advising and counseling for scholars, tutoring assistance, opportunities for summer research internships, active and structured faculty involvement, active and structured administrative involvement, organized mentoring relationships, required community service, and family involvement.

In spite of the success of minority retention efforts like the Meyerhoff Scholars Program, the need for minority retention efforts in science persists. One of the more pronounced and resilient problems facing science education is the underrepresentation of certain minority groups in the science workforce. This is a problem that has seen little to no remission in nearly 40 years. So while current minority retention efforts may have impacted local or regional constituencies, they have done little to reverse the national pattern of minority underrepresentation. One possible explanation for this shortcoming is that overdetermining for success is costly and requires a substantial institutional investment. There are relatively few institutions that will commit to minority retention efforts as extensive as that demonstrated by UMBC. Research aimed at identifying more pronounced causal factors will go a long way in helping educational, government, and corporate agencies to commit to more efficient minority retention efforts, thereby serving greater numbers of underrepresented minorities.

Cross-References

- ▶ Access of Historically Excluded Groups to Tertiary STEM Education
- ▶ Cultural Values and Science Education
- ▶ Gender-Inclusive Practices
- ▶ Participation, Gender-Related
- ▶ Teacher Supply and Retention

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Rika

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In Japan, a subject corresponding to "school science" is called Rika. In elementary and lower-secondary schools (up to 9th grade), the subject name Rika is used extensively. In upper-secondary level, Rika is maintained as the overall subject name but generally divided into several "courses" under the names of Butsuri (physics), Kagaku (chemistry), Seibutsu (biology), and Chigaku (earth sciences).

Elementary schooling modeled on Western education systems started in Japan in 1872. After several revisions within a very short period, the national education system (from elementary to college level) was finally completely established in 1886, and it was at that time when the subject Rika was introduced in elementary school curricula. The origin of the term Rika is still an open question. The overall objective of Rika in elementary school in 1886 was simply a topic list of natural things and phenomena to be taught, but that of the 1891 revised version was quite different and structured: "Rika aims at making pupils; (1) observe (Kansatsu) the usual natural things and phenomena precisely, (2) understand the outline of the interrelation among natural things and phenomena as well as the relation of such natural things to the pupil's lives, and (3) cultivate the love of natural things." From that time the last component, love of natural things (Shizen in Japanese), has been substantially maintained in elementary level for these 120 years (Ogawa 1998). It has been accepted positively by most Japanese as one of the key spirits of the subject Rika and is seen as being in addition to science learning in the sense of Western school science. Thus, Japanese people have been readily confusing science and Rika (especially the spirit of science and that of Rika), even though in the secondary level Rika has never included the component "love of natural things." This is an example of indigenized understanding of science through school science in non-Western cultural contexts.

Cross-References

- ▶ Cultural Influences on Science Education
- ▶ Curriculum and Values
- ▶ Indigenous Knowledge Systems and the Nature of Science
- ▶ Kansatsu
- ▶ Primary/Elementary School Science Curriculum
- ▶ Values and Western Science Knowledge

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Role-Plays and Drama in Science Learning

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Keywords

Constructivism; Drama; Role-play

For many the ultimate goal for science learning is to create a learning environment in which students are not only active, deeply engaged participants but also where they have the potential to lead the activity. Role-play and drama have key roles to play in reaching this goal. Role-play tends to be the shorter form of this type of learning and more readily accessed in a classroom. Drama is more considered and formalized and requires more preparation.

However, in the science classrooms of today as in the past, role-play and drama remain far more absent than present. There is a lingering if outdated view that role-play and drama do not belong in the science classroom. Science is viewed as a rigorous, logical, structured, and serious discipline, while role-play and drama are seen as inaccurate, frivolous, and fluffy, belonging more to the arts than the sciences. Such views are at odds with the ways some teachers use role-play and drama to enhance their students' understanding of science. Ødegaard (2003) notes that there is still a dearth of studies on the use and effectiveness of role play and drama in science education.

The use of role-play and drama as science learning strategies in both primary and secondary education originated from a number of different starting points, all of which arose from the recognition and concern that many students were disengaged from science. From the 1970s onwards, research in learning in science turned to what is now generally described as constructivism. This includes alternative conceptions, problem-based learning, cognitive challenge, disengagement, relevance and ownership, gender issues, multiple ways of knowing, and the general complexities of the classroom. Extensive research clearly pointed to the need for less "chalk and talk" and more engaged, active, experiential, student-centered learning, if deep understanding was to be achieved. Role-play and drama provide powerful means for students to engage deeply with the material, including being extended to assessment, where students may choose to demonstrate their understanding through means of role-play and/or drama.

Role-play and drama engage with a fundamental part of human psychology – the desire for creativity and play. By the time children begin learning science at primary school, they are already experienced at play as the means by which they develop their knowledge and intelligence. As Vygotsky noted, children's play is a creative transformation that helps them make sense of their world. Teachers who use role-play and drama as part of their repertoire report that the vast majority of students enjoy participating in them. They enable students to engage emotionally as well as cognitively; something is now known to increase retention and depth of learning. These approaches also assist the learning of those students with high kinesthetic abilities. Developing role-play and drama through group activity enhances students' teamwork and collective decision-making abilities, and being personally engaged supports the construction of and reflection on understanding.

The form and choice of role-play and/or drama depend on the learning context and content. There are two main ways in which role-play and drama can be used to enhance science learning: (1) understanding of scientific concepts that draw on simulation and analogy and (2) human-science relationships that explore the human impacts of science on culture and society, including science history and futures, and ethical and controversial issues.

Scientific Concept Understanding Through Simulation and Analogy

Complex and abstract concepts can be made concrete and hence clearer using role-play as a mode of learning. Students can play the role of an object or element in a scientific system, such as the movement of electrons in an electric current, atoms in a chemical reaction, planets or moons in the solar system, particles in phase changes, and particles in a sound wave.

The level of student ownership depends on the teacher. A good way of developing the role-play is for a group of students to be given a concept, for example, the changes of phase of matter from solid to liquid to gas and back again. Students are challenged to decide how to demonstrate the phase change, then act it out for the class. Extensions can be introduced by both students and teacher, such as relating particle movement to temperature, which readily leads to the extrapolation to no particle movement, i.e., absolute zero. As well, linking the role-play to other learning procedures such as a graphical representation of phase change assists in bedding down conceptual understanding.

Systems can be readily explored using role-play, such as the dynamics of food webs; operation of machines; body systems such as the digestive, circulatory, immune, and urinary systems; or processes such as photosynthesis and DNA replication. Again, students work together to become elements or objects in the system and simulate its functioning through their movements.

Human-Science Relationships

The human impact of science, too often ignored in the quest for conceptual understanding, can be explored using varying forms of role-play and drama. This aspect of role-play and drama assists students to understand that science is complex and ever-changing, the result of human endeavor, rather than a collection of isolated facts and concepts that somehow exist outside of human experience. Students can research and explore different points of view on a topic and present their findings through debates, court cases, hypotheticals, simulated or real meetings, or even public events such as a presentation of an issue of local interest to a local council. Controversial issues in science such as reproductive technologies, genetic engineering, or nuclear energy can be explored through researching and taking on the roles of different stakeholders in the issue. Through role-play and drama, students can discover the history of the development of a scientific theory and the human complexities and conflicts that lie behind what might seem a clear-cut concept. Darwin's theory of evolution and the trial of Galileo are popular issues to examine through role-play and drama.

Taking It Further: Drama, Theater, and Film

Role-play and drama can be taken out of the classroom and elevated to theater and film. In Australia, the Science Teachers' Association of Victoria (STAV) has been holding Science Drama Awards for schools since 1993. The award is designed to foster creativity and integrate science learning with reading, writing, music, art, and the performing arts. Schools submit a script and video of their proposed performance, and finalists are selected to perform in front of a live audience.

Australia's national science agency, the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO), was heavily involved in science drama and theater for all ages through their education arm Double Helix Drama, a youth theater group based in Tasmania and led by science communicator Jeannie-Marie Le Roi which ran from 1990 to 2004. Le Roi (1998, n.d.) has published two useful resources designed to encourage the establishment of similar groups and to assist teachers who wish to explore the use of role-play and drama. The group also acted as mentors to other young people wanting to be involved in science drama and held science drama camps.

Double Helix Drama places all key production roles, both cast and crew, in the hands of the students, with some guidance from teachers and Le Roi's group. These roles include coordinator, scriptwriter, cast members, backstage, costumes, promotion, and administration. The performances include music, songs, dance, and mime and can be serious or comedy. This range of roles and styles of presentation ensures that all students are able to be included in the production according to their capabilities and interests and that science learning takes place for them all. The groups perform theatrical pieces on a range of topics that may illustrate scientific concepts or current controversial and complex issues or moments in science history. Examples include Our Place in Space and Howard Florey – A Tale of Tall Poppies. These and other plays were written and developed by Chris Krishna–Pillay, a prominent science communicator and performer.

Double Helix Drama has extensively performed throughout Australia and also in Korea and New Zealand. Examples of role-play and drama are now readily accessible via YouTube.

Other examples are Scinema which has a students' film section and the Eureka Awards which has a "Sleek Geek" award for science film, established in 1990 to reward outstanding achievements in Australian science and science communication.

In summary, role-play and drama can form an important part of approaches to developing student learning in the science teachers' repertoire. These have the potential to contribute strongly to a student-centered, inclusive, participatory, active, and enjoyable learning environment and are only limited by the creativity and enthusiasm of the teachers and students.

Cross-References

- ▶ Affect in Learning Science
- ▶ Alternative Conceptions/Frameworks/Misconceptions
- ▶ Communities of Practice
- ▶ Constructivism
- ▶ Science Theater/Drama
- ▶ Visualization and the Learning of Science

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Scaffolding Learning

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Keywords

Argumentation; Calibration; Fading; Learning progressions; Science learning; Zone of proximal development

Definition of Scaffolding

Wood et al. (1976) were the first to use the term *scaffolding*. Within a tutoring context, Wood and colleagues described scaffolding as involving support such as reducing the degrees of freedom available to a learner, emphasizing relevant features of a task, and modeling solutions to a task. They demonstrated how, with this support, children were able to attain higher levels of performance than they could without the scaffolding. In essence, then, scaffolding works as a mediator within a learner's zone of proximal development (Vygotsky 1978). Stone (1998) identified key features of face-to-face scaffolding interactions, including careful determination of the task, accurate diagnosis of the learner's current level of proficiency and calibration of support to match that level, providing a range of types of support, and fading the support over time. Others have argued that scaffolding can be instantiated through physical artifacts or software features that serve as cognitive tools that mediate action. Scaffolding can serve to reduce learners' cognitive load and provide expert guidance. The result of scaffolding in learning environments is that learners become more able not just to accomplish the task with support but also that they learn from the process and improve their future performance.

Scholars have expressed concern, over the last decade or two, that "scaffolding" has been used so broadly and with such limited precision as to have become equivalent in many people's minds with any form of instructional support. These scholars argue that the elements of *calibration* and *fading* are critical in describing a form of instructional support as scaffolding.

Importance of Scaffolding in Science Classrooms

Why is it important to consider scaffolding in science learning environments? In short, it is important because with scaffolding, learners can engage in more sophisticated tasks than they can engage in without support, thus making their learning both more effective and more efficient. Even young children are able to engage in sophisticated scientific practices and learn complex science concepts when provided with strategic

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scaffolding (Metz 1995). Similarly, while high school students are unlikely to learn complex content or engage in challenging investigative practices on their own, with scaffolding, they can do so. Recognizing these capacities is increasingly important as many nations move toward setting more ambitious science education standards. Scaffolding meaningful learning of science content and practice promotes relevance and integration, thus minimizing the development of inert knowledge.

Scaffolding can promote students' (a) learning of core disciplinary ideas, (b) engagement in scientific practices, (c) understanding and application of crosscutting concepts, (d) involvement in processes and procedures expected in a classroom, (e) collaboration, and (f) metacognition and reflection. Examples of scaffolding – for example, for the scientific practice of argumentation and explanation construction – might include teachers' discourse moves (e.g., regularly asking students for evidence to support their claims until doing so becomes part of the regular classroom discourse), written prompts in print curriculum materials (e.g., hints or prompts for how to write such evidence-based explanations that fade over the course of a unit or a year), or features in software tools (e.g., guides, graphic organizers, or other features that allow students to match evidence with claims and capture in-process thinking). Scaffolding can also be provided via other physical artifacts in a classroom or other learning environment (e.g., posters with inscriptions in a classroom or features provided via handheld devices to be used in museum settings).

While many tend to think of scaffolding as serving a mainly structuring capacity – through reducing the degrees of freedom, for example, or providing additional information or guidance – in fact, effective scaffolding also, in a purposeful manner, increases the complexity of tasks (and then supports learners in accomplishing the new, more complex tasks). One example would be when students are asked to generate artifacts that reflect the disciplinary practices of science (e.g., through supporting claims with evidence and reasoning or through distinguishing observations from interpretations). A second example would be when students are asked at key junctures to reflect on their engagement in a task, rather than proceeding without sufficient mindfulness. In these instances, scaffolding serves to make learning more complex, thus increasing the potential for learning, especially in the long term.

Science Teaching and Learning Implications

One complex area of focus within research on scaffolding is the notion of fading. Fading can refer to changes in the character, amount, or level of support being provided and leads to the learner taking increasing responsibility for the task. Investigating how to fade scaffolding in a science classroom context has been notably challenging. Instructionally, fading might occur in one of at least three ways. The teacher might fade scaffolding for individual students, based on individualized diagnosis and calibration (much as a tutor might fade scaffolding for an individual tutee). Curricular materials might fade scaffolding over a sequence of weeks or months, based on curriculum developers' hypotheses about student learning and progress vis-à-vis instruction; such fading, though, would be at the class level, rather than at the individual level. Finally, software might fade scaffolding over time, based on data collected on individuals or small groups of students. (Progress is being made in the technological capacity to do this effectively.) These different instructional instances reflect differences in how learners' strengths and struggles are diagnosed as well as how support is calibrated and adapted. Studies demonstrate that learners who experience well-faded scaffolding over time can be successful in unsupported variants of the tasks. In fact, some studies have identified positive learning effects of purposefully fading scaffolding within print curriculum materials, providing at least an existence proof that such fading does not necessarily need to be individualized to be effective. Current work on learning progressions may inform with more precision when scaffolding can likely be effectively faded.

Different agents (e.g., teacher, curriculum materials, software tools, peers) can scaffold science learning. The efficacy of supports provided via curriculum materials or software tools is enhanced by support provided by teachers. Teachers, curriculum materials, software tools, and peers can all provide different kinds of scaffolding (e.g., generic and content-specific; process-focused and rationale-oriented) that work synergistically, or they can provide redundant scaffolding that serve to reinforce one another. Student learning is enhanced through such distributed scaffolding.

Science teachers, too, benefit from scaffolding for their learning. For example, educative curriculum materials – curriculum materials aimed at promoting teacher learning as well as student learning – can scaffold teachers' learning about engaging students in scientific practices by providing both guidance about how to do so and rationales for why it would be important to do so. The scaffolds can be faded over time via a coherent set of year-long curriculum materials. Similarly, approximations of practice in which novice teachers rehearse instructional moves with colleagues or teach a science lesson to a small group of children reflect scaffolded learning experiences in teacher education. Thus, while scaffolding is often investigated in the context of student learning, the construct also applies in the context of teacher learning.

In sum, in designing scaffolding to support students' and teachers' learning in and for science classrooms, designers must consider:

- What meaningful task(s) need scaffolding
- How the individual learner's or collective group's strengths and needs can be diagnosed
- How the support can be calibrated, adapted, and faded for the individual learner and on what basis and on what timeline
- In what ways degrees of freedom can and should be reduced to reduce the learner's cognitive load
- Which most salient features of the task should be emphasized
- What expert guidance should be provided (and how)
- How the task can be modeled for the learner
- How the task can productively be made more complex to promote learning
- What various forms of support should be provided (and how)
- What medium should be used for providing the scaffolding and via what agent
- How distributed scaffolding can be used productively
- How the scaffolding can account for the multiple learners in a setting

Cross-References

▶ Argumentation
▶ Learning Progressions
▶ Socio-Cultural Perspectives on Learning Science

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Scale Scores

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Keywords

NAEP; PISA; Scale scores; TIMSS

Scale scores are derived from responses to assessment items that summarize the overall performance attained by that respondent. The scale scores represent degrees of proficiency in a particular domain. They offer the opportunity to examine the relationships between student performance and various factors measured.

In large-scale surveys such as the Trends in International Mathematics and Science Study (TIMSS), National Assessment of Educational Progress (NAEP), and International Adult Literacy and Life Skills Survey (IALLS), since each respondent responded to just a subset of the assessment items, multiple imputations were used to derive reliable estimates of student performance on the assessment as a whole. Students' proficiencies are generated using as input the students' responses to the items they were given, the item parameters estimated at the calibration stage, and the conditioning variables. The TIMSS eighth-grade reporting metric was established by setting the average of the mean scores of the participated countries to 500 and the standard deviation to 100. For reporting of Programme for International Student Assessment (PISA), results are used scales with an average score of 500 and a standard deviation of 100. NAEP reports the results on a 0–300 scale. The scales arose from the framework being meaningful for feedback and reporting purposes and also defensible with respect to their measurement properties.

Cross-References

- ▶ Assessment: An Overview
- ▶ Assessment: PISA Science
- ▶ National Assessment of Educational Progress (NAEP)
- ▶ Third International Mathematics and Science Study (TIMSS)

School Environments

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Keywords

School climate

Schools are easily recognized within communities anywhere in the world. They are housed in familiar buildings and share a common purpose – to provide a place for learning (see Hayes et al. 2006). While they have a sameness that identifies them as schools, each is different. These differences can be subtle, but increasingly researchers document cases where the differences are stark. For example, schools in remote rural communities in Australia have difficulty recruiting and retaining qualified physics and chemistry teachers. Unsurprisingly, for this and other reasons, students from these schools perform below the national mean on international tests that measure scientific literacy. Similarly, students from poor urban schools in large cities in North America often do not demonstrate satisfactory science achievement on high stakes tests. Notwithstanding the importance of appropriate funding models that might ameliorate large differences in school environments, this contribution considers how schools can make a difference by improving science learning for students.

Even though the familiar architecture of schools can lead to a sense of sameness about schools, it is what goes on within the buildings and how the extended school community interacts with school personnel that differentiates schools and promotes or hinders students' learning of science (see Cohen et al. 2009). In other words, school climate matters. *School climate* is a collective phenomenon based on patterns of participants' experiences of school life that gives a school its character (Cohen et al. 2009). Four essential and overlapping dimensions of school climate are safety, teaching and learning, relationships, and environmental-structural. The subcategories of the teaching and learning dimension of school climate, most relevant to science education, include the following: quality of instruction; social, emotional, and ethical learning; professional development; and leadership (Cohen et al. 2009). Innovations related to each of these categories are now overviewed.

Quality of Instruction

Students in science classes are frequently portrayed as disengaged because the content lacks relevance to their lives and is delivered through traditional pedagogies that rely heavily on teacher transmission of information. Yet whole-school innovative projects that focus on improving the quality of students' experiences have been documented.

Conceived in 1985 to enhance science students' metacognition, the Project for Enhancing Effective Learning (PEEL) articulates principles of purposeful teaching for quality learning, which emphasize sharing responsibilities for learning with students and generating new pedagogical knowledge while being supportive and collaborative with colleagues. PEEL has sustained decades of success across schools in Australia and more recently in Canada, Denmark, Sweden, and Malaysia.

A more general approach to improving the quality of whole-school teaching, known as *productive pedagogies*, was implemented across numerous schools, particularly in Queensland, Australia (see Hayes et al. 2006). This large-scale innovative project recognized that classroom practice was at the heart of schooling and quality teaching makes a difference to school experiences of students. The productive pedagogies are clustered around four dimensions, namely, *intellectual quality* (higher-order thinking, deep knowledge, deep understanding, knowledge as problematic, substantive conversation, and metalanguage), *connectedness* (knowledge integration, background knowledge, connectedness to the world, and problem-based curriculum), *supportive classroom environment* (engagement, student self-regulation, student direction of activities, social support, explicit criteria), and *working with and valuing difference* (cultural knowledges, inclusivity, narrative, group identities in a learning community, citizenship).

Shared characteristics between successful projects such as PEEL and productive pedagogies should be expected. For example, the first dimension of intellectual quality from productive pedagogies aligns with several of the 12 principles of teaching for quality learning (e.g., share intellectual control with students, encourage students to learn from other students' questions and comments, use a variety of intellectually challenging teaching procedures). As well, several international innovations in science education have focused on specific dimensions and principles. For example, research conducted on context-based approaches to science shows how teachers and students make connections between real-world contexts and concepts. Other innovative approaches to engage students in learning science feature next.

Social, Emotional, and Ethical Learning

A major focus for science education research has been conceptual change from an exclusively cognitive perspective. Yet recent advances in neuroscience have shown that emotions are equally important in learning because almost all brain regions are affected by emotions. So, science teachers who practice quality teaching might be expected to weave affective experiences intricately through classroom activities.

Recent continuing research has shown how students emotionally engage with activities designed around socioscientific issues (e.g., Tomas and Ritchie 2012) that also aim to develop their conceptual understanding of related phenomena and attitudes to science. Socioscientific issues education aims to develop students' moral, ethical, and epistemological orientations through activities in which the moral implications are embedded in scientific contexts (e.g., biosecurity, coal seam gas, organ transplants, and harvesting). A focus on socioscientific issues in the curriculum could help students not only grapple with some of the most complex social challenges of the century but also develop connectedness with their communities (cf. productive pedagogies). Innovative programs in large US urban schools involving socioscientific issues and other curriculum emphases (e.g., C3 curriculum: choice, control, and change) that afford students' opportunities to consider how these issues (e.g., food) impact on themselves have empowered students to connect students' lives to science in relevant and meaningful ways (see Mallya et al. 2012).

Another way teachers and researchers have improved the social and emotional life of students' in science classes is through the dual process of coteaching and cogenerative dialogue (Tobin and Roth 2005). *Coteaching* requires collaboration between teachers who share responsibility for planning and enacting the curriculum. *Cogenerative dialogue* involves different stakeholders from a class meeting from time to time to discuss how learning can be improved in class and to develop action plans that all members take responsibility for enacting. Used together, coteaching and cogenerative dialogue helps teachers to learn how to build collective decisions with colleagues and collaborate with their students to create and sustain effective classroom learning environments. In other words, they provide a context for on-the-job professional development.

Professional Development

If quality teaching through student-centered pedagogies can make a difference to student learning, then structures (or the social arrangements, relations, and practices that exert power and constraint over what individuals and groups can do) that encourage teachers to collaborate for and with their students should be promoted (e.g., coteaching and cogenerative dialogue). Teacher-led professional communities (e.g., those associated with PEEL) also can be effective sites for improving the quality of teaching and learning. Yet it still may be necessary for schools to invest in creating opportunities for teachers to exchange ideas and discuss professional practice as a normal part of the school day (Hayes et al. 2006). This takes leadership.

Leadership

Even though school principals and heads of science departments are important in transforming and supporting climates conducive to the improvement of teaching and learning, all teachers need to lead. The *collective leadership* in schools necessary to improve teaching for student learning involves the shared responsibility of personnel to generate and enact structures that afford agency (or the power to act) to stakeholders (both individuals and groups). The enactment of collective leadership manifests not only as practices such as cogenerative dialogues but also as solidarity among participants and the generation of positive emotional energy through successful interactions (Ritchie 2012).

Cross-References

- ▶ Classroom Learning Environments
- ▶ Integrated Curricula
- ▶ Project for Enhancing Effective Learning (PEEL)
- ▶ Science Teaching and Learning Project (STaL)
- ▶ Socioscientific Issues

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School-Community Projects/Programs

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Introduction

In the past few years, science educators, researchers, and policy makers have been increasingly drawn to the educational potential of school-community projects and programs. "Community-referenced education," "community-based education," "community education," and "place-based education" are all popular contemporary signifiers that serve to distinguish clusters of pedagogical practices that involve schools, classrooms, and students working together with individuals, groups, and organizations mostly located outside of schools. While such programs are driven by a variety of differently nuanced goals, interests, and aspirations, they share a commitment to the considerable educational merits of collaborative practices between diverse communities located in different social, ecological, material, and economic contexts and settings. Through such commitments, these programs nurture pedagogies that are not only about *what* we learn, but also about *why*, *where,* and with *whom* we learn.

School-community programs involve schools working with a large number of different groups including families, youth groups, heritage sites, science institutions, new social movements, government organizations, cultural groups, hobby groups, and businesses. In some cases, these communities are seen, perhaps, more as a "field-resource" with the potential to significantly enrich students' school-based learning as well as future social mobility. Such projects are conceived and structured to advance the interests of schooling by leveraging the expertise, assets, and resources of community collaborators. Other projects have different, potentially more far-reaching, desires that include school-based reform and community development and building (sometimes alongside school interests). In these cases, school-community collaborations offer opportunities to reflect and act in pursuit of better communities of practices both inside and outside of schools.

Given that school-community projects and programs capture such a wide range of educational initiatives, they defy a straightforward generic checklist of benefits and gains. Programs carry their own distinctive set of evaluative questions concerning how and whether they are working, why and for whom, and under what conditions. Some projects, for example, highlight the benefits of increased and more meaningful, authentic, longer lasting learning. Others explore gains in terms of increased social equality and inclusion, and others focus more on "community building" and/or local ecological restorations and local material enhancements. In the following text we offer brief discussions of selected school-community projects within three broad groups. We then turn attention to some of the tensions that this broad approach to science education presents.

Learning Science Out of School

There are a large number of documented projects in which school students work with a variety of different science-related community groups in out-of-school settings. Within these projects, students encounter science in "everyday" contexts and in so doing, advocates maintain, they develop the ability to learn and use science within "more authentic" settings. including museums, zoos, government organizations, and media. As practitioners and researchers persuasively argue, this type of learning is more meaningful because it is potentially more personalized, contextualized, voluntary, and self-paced. Indeed, much research suggests that exploring science in out-of-school settings can awaken a critical review of the benefits of learning science, as well as how learning might become more empowering. A large number of authors draw attention to the benefits of education projects that challenge youth to collaborate with communities in ways that make their contributions count. Léonie Rennie (2006) describes, to give a couple of environmental examples, educational projects in which youth work with community groups to raise awareness about poor air quality from smoke haze and wood burners and organize a campaign to reduce the indiscriminate killing of venomous tiger snakes. The success of such school-community projects Rennie accredits to a list of generic guiding principles:

- The issue under examination comes from the community and is not imposed.
- Local knowledge is required.
- It is educative.
- Schools are integrated to allow student and teacher participation.
- It involves negotiation and decision-making with the community.
- Outcomes indicate something worthwhile and tangible (Rennie 2006, p. 9).

Science Education as/for Community Development

In a series of influential studies, Wolff-Michael Roth and Angela Calabrese Barton (Barton and Tan 2010; Roth and Barton 2004) investigate students and teachers working with particular local rural environmental groups and urban youth groups on particular community-referenced projects. The studies involve students (and teachers) working with others within specific social, ecological, and economic contexts and settings with pedagogical goals of researching and better understanding shared issues and concerns and shaping common actions. They highlight some of the benefits that this pedagogical orientation provides. These include opportunities to experience the situated nature of knowledge and the interactions of multiple knowledge claims (in which science is one amongst many expert knowledge claims), and the nature and importance of collaboration with ethical responsibilities that active community participation entails (see Roth and Barton 2004). Such projects resist what Paulo Freire calls "banking models of education" and view young people as partners in education as/for social change allied with common social and ecological justice aspirations. This more political orientation provides opportunities to rethink more traditional meanings of "scientific literacy." Over the past decade or so, there is much empirical evidence coming from a variety of different sources that suggests that more locally situated, community-based, politically orientated science education has profoundly positive educational implications for all students, particularly including those who are marginalized by many traditional school-based practices.

Place-Based Science Education

Over the past few years, there has been a steady increase in "place-based" educational projects and theorizing. In much of the recent "place-based" educational literature, there is an emphasis on the prospect of resituating learning within particular communities with critical place theorized aspirations. As David Gruenewald – a high profile advocate of "place-based" education – writes: "human communities, or places, are politicised, social constructions that often marginalize individuals, groups, as well as ecosystems" (2003, p. 7). Approaches to place-based education often entail youth deconstructing the power dynamics inherent to the relationships that people have with places and then collaboratively reconstructing different, more environmentally and socially just relationships. There are a growing number of projects in science education that draw from and extend this approach. "Science in the City" (Alsop and Ibrahim 2008) is one community/place project in which the often "taken for granted-ness" of local places is revisited through activities such as neighborhood walks and photography. This provides a basis to identify issues for further science-based inquiry. Such inquiry has included research with a local medical laboratory to better understand a sister's illness and offer advice, building gardens to recapture hope from personal loss, and working with local fishmongers to better understand declining aquatic ecosystems and food chains. The project concludes with a celebration of practices and the circulation of a collaboratively written, community-orientated publication.

Some Tensions

Despite many advantages and increased attention in research and policy, there is still a relatively modest uptake of school-community programs in practice. Studies have explored this paradox and brought attention to a number of barriers, including increased safety concerns and administrative requirements, teachers lacking confidence and expertise in this approach, demands of establishing and maintaining community partnerships, and the seemingly ubiquitous and inescapable time pressures of covering traditional curriculum content.

As institutions of science education are being encouraged toward involvement with communities, many (if not most) are also becoming increasingly standardized (through jurisdictional and national curricula) and also more corporatized in nature. The general notion of community-based practices seeks to balance (to a greater or lesser extent) personal responsibility with collective interests and common identity. In contrast, critics of contemporary schooling highlight traditions of individualism, gatekeeping practices, meritocracy, and elitism. What increasingly matters to many schools and governments are economies of performance, examination results, and acceptance rates for further higher-level study. Given these seemingly deep-rooted cultural differences, it is perhaps not surprising that school-community programmatic collaborations can be difficult to establish and sustain.

There are also some theoretical tensions. As the above examples suggest, the concept of "community" has become freely associated with a host of different educational projects, benefits, and desires. The proliferation of the "community" label has resulted in a reduction of meaning and identity. Moreover, the longing for efficacious educational practices at times results in more than a hint of "essentialism" and "valorization." Communities are complex, multifarious social, ecological, and material manifestations, and while they offer interesting possibilities (particularly in their contrast to school practices), they are neither unitary nor without their own troubles. Some communities will be more educationally desirable; others will certainly be less so. Indeed, in some cases communities will be completely at odds with educational aspirations. The tendency in some educational writing and policy circles to take the concept of community collaboration as "unquestionably desirable" needs our continued reflexive attention.

School-community projects/programs add to an ever-growing list of so-called adjectival educations that demarcate pedagogical, policy, and scholarly turf. Many of these will feature in other parts of this encyclopedia. Subfields can build alliances and allegiances in which practitioners and researchers associate themselves with particular theories and goals; however, these orientations can sometimes take precedence over building broader educational solidarities. Indeed, in this respect, it should be remembered that the concept of community is itself a term of demarcation, which by its very nature is politically both inclusionary and exclusionary. To identify a community is to include and exclude some people on some grounds. Having said this, a shared sense of belonging and a shared sense of identity need not necessarily prevent welcoming others.

There are also associated tensions of "geographical localism." Many school-community programs place an overwhelming emphasis on "the local" and as such raise questions of geographic anchoring and parochialism. Within an era of increased political, economic, and social connectedness, these projects raise questions regarding the local and regional, at a time in which the global and cosmopolitan seems somehow inescapable.

The Future

Clearly school-community programs and projects have an enormous contribution to make to practice and research. While they are not without their own tensions and contradictions, there is considerable empirical evidence in support of far-reaching educational benefits and gains. They offer the prospect of enhancing teaching and learning and also provide a basis for rethinking the nature of science education and schooling itself. Clearly in the future they demand much greater attention in practice and research.

Community-based education has paid less attention to "on-line" communities. Given the popularity of social media, especially with youth, there is a pressing need, perhaps, to better understand and actively explore the possibilities of virtual community-based science education collaborations. This research agenda seems underdeveloped and yet is potentially far-reaching. The growing and impressive literature on school-community projects and programs provides a potential starting point from which to embark on these studies, while recognizing demonstrable differences between "virtual" and "real" educational contexts and settings.

Cross-References

- ▶ Immersive Environments
- ▶ Learning Science in Informal Contexts
- ▶ Science Community Outreach
- ▶ Scientific Literacy

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Schooling of Science

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Although much research is still needed, the schooling of the sciences (i.e., the way in which science subjects have been incorporated in the school curriculum) has received more attention than most other subjects of the curriculum (DeBoer 1991). Both historical and ethnographic studies (Goodson and Ball 1984) indicate the socially and politically constructed nature of school science curricula and, more particularly, the ways in which both content and pedagogy reflect several widely held assumptions about, for example, pupils' ability, their likely future occupations, the role of women in society, and, ultimately, about the purpose of particular types of curriculum or schooling.

The attention given to school science reflects the fact that aspects of the sciences, such as laboratory work, present unique problems. It is also an acknowledgement that accommodating the scientific disciplines in the curriculum challenged the historical basis of school education. That basis lay in the teaching of the classics and mathematics, subjects whose status as the foundation of a liberal education was legitimized and defended by the universities. In most education systems, the challenge emerged with particular force in the nineteenth century and was directed primarily at those schools such as grammar schools and gymnasia that enjoyed a close historic link with higher education.

The curriculum histories of chemistry, physics, and biology in these schools are different, largely as a result of differences between these subjects and their relative maturity when science was first schooled in the mid-nineteenth century. Despite the scientific revolution of the seventeenth century, physics was professionalized later than chemistry, and in many respects, it can be regarded as a subject constructed from a range of intellectually and socially diverse fields (heat, light and sound, magnetism and electricity, mechanics, and properties of matter) for the purposes of education. In contrast, inorganic and organic chemistry, with a common focus on understanding the preparation, properties, and analysis of materials, offered a more straightforward resource for curriculum construction: physical chemistry was not to gain a place in school curricula until the twentieth century. The timing of the introduction of chemistry into schools also reflected its contemporary salience as a discipline: if the case for teaching science in schools had succeeded in England a generation earlier, it may well have favored geology rather than chemistry. Although biology had long been institutionalized as zoology and botany, the universities offered no "model" upon which a school biology curriculum might be based. In addition, as a school subject, zoology, with its emphasis on anatomy and physiology, was widely judged appropriate only for future medical students, while simultaneously raising concerns about exposing young women to the more intimate aspects of the discipline. The study of systematic and economic botany, along with plant morphology and natural history, represented altogether safer educational territory. However, both botany and zoology were also open to the charge that neither provided an opportunity for experimental work in a teaching laboratory, perceived as an essential condition for accommodation within school curricula. It was not until the mid-twentieth century that satisfactory schemes of work involving observation and experiment and based firmly on general biological principles could be developed. Biology as a discipline therefore secured a place in most school curricula much later than either chemistry or physics.

Unsurprisingly, school science curricula in grammar schools and gymnasia became something of a preprofessional training, supported by a pedagogy similar to that used to teach undergraduates. School chemistry emphasized the preparation, properties, and uses of the elements and their compounds, together with qualitative and quantitative analysis. Physics stressed the importance of precise measurement, an understanding of the basic laws governing, for example, motion, electrical conductivity, and the transfer of heat, light, and sound, along with an ability to solve what quickly became a standardized set of associated calculations. Differences in the science curricula of these schools in different education systems were marginal, rather than fundamental, often reflecting country-specific manufacturing processes or national claims about the priority of scientific discovery.

Where the historic link between schools and universities did not exist, as in the case of the large numbers of schools created to provide public elementary education, the challenge of accommodating the sciences in the curriculum was different and the schooling of the sciences followed a different path (Layton 1973). The scientific disciplines were raided or adapted to construct curricula designed to meet different future social roles and employment needs. Titles such as "How electricity is made and distributed," "The science of common things," "The chemistry of everyday life," "Science in the Home," "Human Biology," and "Social Biology" are representative of many initiatives of this kind. In some education systems, broader courses with titles such as "Science" or "General Science" were developed but, despite some success, these ultimately failed to overcome the conceptual, linguistic, methodological, and philosophical differences between the contributing scientific disciplines and they fell out of favor as a demand arose for a greatly increased number of qualified scientific personnel. The challenge for pedagogy, too, was different. Laboratory-based work designed to introduce pupils to the grammar, syntax, and methods of science was replaced by practical activities more directly related to employment, to anticipated social roles, and, in some instances, to wider social and political concerns such as health, diet, and child rearing.

Pedagogy in all types of schools has also been subject to more specific educational influences, notably assumptions about how children learn and should be taught. In many Anglophone countries, the criteria used to determine the order in which topics should be taught was initially determined by the conceptual difficulty that each was presumed to present to students. Thus a course in elementary physical measurements would be followed by the study of heat, light, sound, and mechanics, followed by, or alongside, elementary chemistry. Although this criterion gave way to others, for example, the notion that the interest of children in science exhibited a rhythm corresponding to the rhythm of its history, it was not until the mid-twentieth century that research-based insights into children's learning and understanding of scientific concepts came to play a significant role in determining pedagogy.

In other systems, notably in continental Europe, where educational theorizing was differently conceptualized, the notion of "didactic" was of central importance in the schooling of science. The underpinning notion of didactic is the belief that it is possible to construct a scientific discipline (didactic) by drawing upon a range of other disciplines relevant to the processes of teaching and learning. The difference between these continental and Anglophone traditions remains important, and it is not merely semantic: it reflects contrasting views of what constitutes "scientific research" in education and thus of the role that disciplines such as philosophy, psychology, and sociology can and should play in curriculum construction and pedagogy.

The latter half of the twentieth century was characterized by profound changes in science, in society, and in their interactions and, in some education systems, by major changes in the structure of schooling. A growing postwar demand for qualified scientific personnel, prompted in part by the Cold War, prompted a global movement for school science reform (Rudolph 2002). In the 25 years or so that followed the end of World War II, the scientific content of school curricula was modernized, new assessment techniques developed, and pupils encouraged to learn by engaging in "hands-on" laboratory activities. In some cases, notably at the primary level of schooling, the reform drew upon Piagetian ideas about young people's understanding of fundamental scientific concepts such as mass and time, ideas that eventually led to the development of a substantial field of constructivist research. At the same time, the abolition of selective systems of schooling raised challenging questions about the educational function of school science and highlighted the problem of accommodating the different approaches to science teaching referred to above within a common secondary school.

By the 1970s, a number of other factors had begun to shape the schooling of science. These included the rise of environmental concerns, increased attention to long-standing gender and other equity issues, and the challenge presented by postmodern perspectives on science itself. In addition, there was anxiety, notably in the developed world, about a decline in the popularity of the physical sciences as subjects of advanced study and a recognition of the need for a curriculum response to the growing number of complex ethical and political problems posed by scientific and technological developments. That response took the form of an international science-technology-society (STS) movement (Solomon and Aikenhead 1994). Impelled by a mixture of motives and manifest in diverse curricula, the movement eventually owed less to the community of professional scientists within higher education than to initiatives by science teachers and researchers. Examples include the Science for Public Understanding Program in the USA and the Science and Society Project in the UK. Many of these initiatives made use of the growing power of information and communication technologies, especially the Internet which has become an increasingly important factor influencing how science is taught and learnt.

As the numbers of young people wishing to study science continued to decline in the closing decades of the twentieth century, doubts were raised about the merits of earlier curriculum initiatives as well as the mechanisms used to promote reform. When these doubts were reinforced by the disappointing results of surveys of the level of public understanding of science, attention inevitably focused on the issue of standards of achievement. This later acquired added political and educational salience as a result of international comparative studies such as PISA and TIMSS, the outcomes of which led directly to changes in the school curricula of several countries. The challenge facing all education systems, therefore, was how best to promote the higher and more general scientific literacy deemed necessary for a variety of economic, political, social, and personal reasons. In some systems, government responded to the challenge by taking direct control of the science curriculum and its assessment, specifying intended and measurable learning outcomes and offering suggestions for best pedagogical practice. Where central government control of schooling was not possible, as in the USA, it was necessary to respond in ways that accommodated the delocalized nature of curriculum control.

As governments have demanded greater accountability of investment in schooling, they have inevitably gained greater influence over what and how school science is taught and assessed. This has created an educational bureaucracy that, in many countries, has overturned the historic roles accorded to academia and science teachers to determine the form, content, and pedagogy of school science. The longer-term consequences of this shift in authority remain to be determined.

Cross-References

- ▶ Bildung
- ▶ Competence in Science
- ▶ Curriculum Movements in Science Education
- ▶ Didaktik
- ▶ Primary/Elementary School Science Curriculum Projects
- ▶ Relevance

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Science and Mathematics Teacher Education

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Keywords

Mathematics; Pedagogical knowledge

This entry will consider how and why science and mathematics have been linked in teacher preparation programs in ways that influence notions of content knowledge and pedagogy.

How Similar Is Teaching in Mathematics Compared to Science?

While the obvious importance of mathematics to scientific endeavor might seem to indicate an obvious link between science and mathematics teaching and learning, the structure and guiding principles for school curricula in the two areas are substantially different (Siskin 1994).

Mathematics tends to have a highly sequential curriculum structure, whereas science curricula are organized around topics that are not tightly sequenced. The pedagogies in the two areas tend to differ, with mathematics teaching emphasizing sequenced practice in problem solving and science teaching incorporating substantial experimental work and practical application of concepts.

Studies of science and mathematics specialist teachers teaching across this disciplinary boundary have indicated a significant "boundary crossing" issue with teachers committed to distinctive aesthetic features of their preferred subject and to different narratives around which the subjects are made meaningful for students (Darby 2008; Darby-Hobbs 2013).

Policy and Practicalities Linking Science and Mathematics

Nevertheless, there are practical reasons why the two subjects are linked in the public mind and in teacher preparation programs. First, both subjects are grouped under the general STEM (science, technology, engineering, and mathematics) banner describing the areas that form the backbone of a nation's technological enterprises. As such, the problems of attracting and engaging students into science and mathematics subjects are related. Student attraction and retention in mathematics and physical science/engineering subjects have similar historical profiles. Similarly, there has been a similar trajectory of problems in attracting and retaining teachers of mathematics and of science. A search on science and mathematics education immediately identifies numerous government policy initiatives in many countries that treat the areas as strongly linked through their contribution to STEM professions. Policy initiatives focused on student and teacher attraction and retention into the STEM area lend credence the idea of linking the areas in teacher training.

Because of the substantial mathematics component of most science degrees, preservice teachers (PSTs) will often be qualified to teach in both areas, and combining them in a teacher preparation program offers efficiencies. In postgraduate entry programs also, mature age students with engineering or technology backgrounds will often have expertise and qualifications in and commitment to both areas. The opposite face of this coin is that elementary teacher trainees have been reported to experience similar issues with confidence and self-efficacy in the two subjects.

The reality in schools (in some countries at least – including Australia) is that in the face of a shortage of qualified mathematics or science teachers, teachers qualified in these subjects are the most likely to be called upon to teach across the science-mathematics subject boundary – to teach "out of field" (Ingersoll 2003; Hobbs 2012). Given the argument above, that the two subjects differ considerably in the structures and pedagogies of their traditional school forms, this would indicate another reason why PSTs in the two subjects should be exposed to the pedagogical traditions across the boundary and be provided with strategies for making the crossing.

In any teacher education program, there exists a tension between the need to introduce teachers to the pedagogical traditions and substantive knowledge of their specialist field and the need to develop their general pedagogical orientation and their identities as teachers per se. With regard to teaching and learning, this issue is informed by Shulman's (1987) description of teacher knowledges which include content knowledge (CK), general pedagogical knowledge (PK), and pedagogical content knowledge (PCK) which refers to knowledge of curriculum organization and structural traditions, of student learning challenges, and of teaching approaches specific to the subject. There are choices to be made as to where to put the emphasis in a teacher education program – whether to focus on maximizing knowledge of the chosen disciplinary area (e.g., science, or mathematics, separately) or whether to develop structures that allow more emphasis on general pedagogical knowledge with less time devoted to discipline specifics.

Given the likelihood that teachers in their career may be called upon to teach across a number of subjects, there is an argument that a prime aim of a teacher education program should be to produce teachers who are adaptable, able to take up challenges of teaching across fields such as science and mathematics. This is one aspect of the argument for bracketing science and mathematics teacher education.

Another argument was particularly strong in writing in the 1990s, advocating the integration of science and mathematics at the school subject level (Pang and Good 2000). This was a specific instance of arguments for curriculum integration more generally, pointing to the flexibility of integrated curricula and the enhanced possibility of building student knowledge around authentic, contextualized problems that drew on a range of disciplinary traditions.

Research in Science and Mathematics Education

Research often links science and mathematics teaching and learning. A number of journals cover both areas (Research in Science and Mathematics Education, School Science and Mathematics, Canadian Journal of Science, Mathematics and Technology Education). In the research literature, theoretical advances and perspectives have followed similar trajectories in science and mathematics education more so than for other disciplines. Constructivism for instance was a big issue in the 1990s in both subjects (Wheatley 1991), although the pathways it took and the presumptions made were different. Conceptual change approaches have been important in science education but have been pursued in mathematics also (Vosniadou 2008). Similarly, current concerns with social constructivist and sociocultural perspectives and the role of representations are current concerns driving much new thinking in both subjects. The work of Richard Lehrer and Leona Schauble, for instance, explores model-based reasoning and classroom representation construction in the context of both science and mathematics (Lehrer and Schauble 2004, 2005).

Educators calling for reform in the two areas have similar agendas; the emphasis in science is on inquiry approaches and the inclusion of socioscientific contexts into the curriculum to make science more meaningful. These reform agendas (Tytler 2007) critique the traditional transmissive pedagogies common in school science. In mathematics, there have similarly been strong movements towards problem solving and “real maths” with a contextual underpinning. The critique here has been the instrumental focus of traditional mathematics teaching. Calls for reform in both subjects emphasize higher-order thinking and scientific literacy/numeracy, as a major aim. Thus, insofar as teacher education programs draw on current research, productive links can be made between the research literatures in mathematics and science.

Cross-References

- ▶ Secondary Science Teacher Education
- ▶ Science, Technology, Engineering, and Maths (STEM)
- ▶ Third International Mathematics and Science Study (TIMSS)

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Science and Society in Teacher Education

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Keywords

Science education; Society

Background

Contemporary science education serves the dual role of training future scientists and educating future users of scientific knowledge. This presents science teachers with the challenge of developing both students' understanding of scientific knowledge and their awareness of the interactions between science and society to deliver the benefits of science while avoiding the pitfalls. The connection between science and society has become increasingly complex in light of the rapid advancements, in science and related technologies that permeate our lives, intertwining with consumerism, economic developments, and politics. This saturation is evident in the many science-related claims advertised by consumer products and the large-scale national development plans advanced by politicians to boost the economy that may ultimately endanger our natural environment.

The Aim of Science and Society Education

These developments have required that science students engage in increasingly complex inquiries from multiple outlooks when addressing science and society, including technological, epistemological, politico-economic, sociocultural, and moral/ethical perspectives. Such inquiries have evolved into different forms, as reflected by the jargon involved in the curricular movements that have sprung up in recent decades, such as *Science for All*, *Science-Technology-Society (STS)*, *Scientific Literary*, *Socio-scientific Issues (SSI)*, and, the latest, *Science Proficiency* (National Research Council 2007). The emphases of these curriculum movements with respect to science and society appear to have shifted from learning scientific concepts using related technologies and understanding such technological applications and their social and ethical implications to developing critical thoughts about scientific practices within society and their place within sociocultural contexts. The most recent of these emphases have included evaluating scientific evidence in authentic contexts, weighing the pros and cons of decision alternatives from both scientific and nonscientific perspectives, and formulating criteria underpinned by moral or value judgments to imbue students with a more thorough understanding of the role and limitations of science in society that cultivates informed decision-making congruent with this understanding. Thus, science and society education aims to develop not only scientifically knowledgeable citizens, but also critical thinkers who are aware of the scientific practices applied in society and capable of engaging in discourse at the science-society interface.

Implications for Teacher Education

To achieve this aim, teachers must develop a knowledge base comprising three interrelated components: content knowledge of the relationships between science and society; thinking processes involving argumentation, reasoning, and decision-making about socio-scientific issues; and the pedagogical knowledge and skills needed to lead students to achieve the aforementioned aims. Each of these knowledge components begs a multitude of questions that serve as a foundation for science teachers preparing to address matters of science and society. The content knowledge explores what roles science has played in the shaping of societal development and how the work of the scientific community has been influenced by the social, cultural, and political milieus. It also analyzes how the nature of science enhances and limits its role in society. Regarding thought processes, as students must learn how to determine the trustworthiness of science-related claims by evaluating scientific evidence and how to negotiate disagreements over conflicting science-related claims, teachers must discover what types of argumentation, reasoning, and decision-making frameworks are available to guide these processes. As for pedagogy, teachers must show students how to evaluate claims and evidence in authentic contexts that are much messier than the seemingly uncontested textbook knowledge and controlled experiments they have become accustomed to in laboratory environments. It raises the question: How can teachers possibly assume leading roles in an emergent area of science education in which they can claim no expertise?

Implications for Learning

Meeting these challenges requires that science teacher education be rethought, with new pedagogies grounded in research to enable teachers to take full advantage of the potential learning opportunities that science and society education offer. The learning experiences provided by these pedagogies should exhibit four essential characteristics. First, they should be contextualized and situated preferably in current socio-scientific issues to increase relevance and motivation. This would address the problem of learning canonical science in a decontextualized manner, as is commonly practiced in science classes.

Second, learning should be integrative so that the science and society components are not seen as merely an “expensive elaboration” of the curriculum in terms of time or as an “armchair discussion” that bears little relationship to a declarative or procedural understanding of science. Science and society education must be successfully integrated with conventional science educational goals to achieve a holistic science curriculum that produces and promotes scientific literacy. Such integration could be achieved by situating the learning of relevant scientific concepts and processes, along with the nature of science, in the context of socio-scientific issues. Because the scientific concepts involved might not be readily linked to textbook knowledge, self-directed learning strategies such as problem-based learning (PBL) might need to be employed to encourage students to apply previous knowledge and problem-solving skills to the construction of new knowledge that is essential to the issue being studied.

Third, learning should be interdisciplinary because the compartmentalization of knowledge is by no means conducive to learning in authentic socio-scientific contexts, which entails multi-perspective thinking. As a prerequisite, science teachers should give up a certain degree of territoriality to draw on knowledge and skills from disciplines such as citizenship and value education.

Fourth, the learning process should be collaborative and interactive because recent research has shown that the reasoning and decision-making involved in addressing SSIs are mediated by contextual variables (Lee and Grace in press). Given this, teachers must facilitate the social construction of knowledge and collaborative decision-making through group discussion and, if possible, cross-contextual or cross-cultural sharing that brings students’ backgrounds to bear in argumentation and decision-making. This collaborative knowledge construction process is congruent with how science knowledge is generated within the scientific community, how public policies are created in democratic societies, and how global issues are negotiated by international communities.

Conclusion

Considering the diversified and complex nature of the inquiries required by science and society education, the teaching of science and society defies any uniform teaching protocol or approach. Teachers must be flexible in organizing learning experiences that fit into their school science curricula and the wider societal context in which relevant socio-scientific issues arise.

Cross-References

- ► Environmental Teacher Education
- ► Pedagogy of Teacher Education
- ► Science, Technology and Society (STS)

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Science and Technology

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Keywords

Technology; Values

Introduction

Over the last three decades, there have been significant changes in teacher education and the place of science within this. For example, there has been varying emphasis on general science, integrated science, and STEM. This entry focuses on possible interactions between science and technology in teacher education.

Technology, here, encompasses more than just ICT. Rather, it is seen to be a dominant part of our culture and the world we inhabit. People develop and use technologies to intervene in this world to expand human and environmental possibilities. Technological endeavors encompass a broad range of activities including the transformation of energy, materials, and information in products, systems, and environments (Jones et al. 2010). Many school curricula package these as electronics and control technology, food and process technology, and materials technology and production. Within science education, technological examples are often presented to demonstrate scientific concepts. Context-based approaches to science education also often use technological examples to engage students in learning. Curriculum innovations such as science, technology, and society (STS) and Science, Technology, Engineering and Mathematics (STEM) expand on this to integrate technology in science. However, within these approaches, technology is often characterized and taught as applied science.

Science Teacher Education

In thinking about the role and place of technology in science teacher education, it is important to consider the characteristics and nature of technology (refer to entry on Technology Education and Science Education for a discussion of similarities and differences between science education and technology education, as well as the nature of technology). However, the distinction between science and technology is not often considered to be important in the teaching and learning of science. Neither is it at the forefront of science teacher education at both the pre- and in-service levels. This is likely because of the perceived similarities between the two fields, conflated with the perennial challenge of deciding which content to prioritize when only a limited amount of time is allotted to science and/or technology as part of a teacher education program.

The risk of not exploring the differences between science and technology can mean that preservice teachers and their eventual students develop limited understandings of the nature of each field. For example, science is often seen as the precursor to technology (technology as applied science). This can be reinforced by the frequent use of technological applications to exemplify a scientific concept. However, it does not lead to understanding of other possible relationships between science and technology. Similarly it does not provide students with opportunities to consider how technology shapes their world and how they might contribute and/or respond to this. As argued elsewhere, understanding the relationship between science and technology and society is about not only learning the "rules of the game" but being in a position to critique these rules and feel empowered to change them (Buntting and Jones 2009).

It is also important to consider both the nature of science and the nature of technology as part of teacher education so that early childhood and primary teachers, who often integrate curriculum areas in their classroom programs, can develop robust understandings of both in order that their teaching maintains the integrity of each discipline as an area of inquiry and development with its own sets of values and processes (Jones 2007). At the secondary level, newer technologies such as biotechnology often require that science specialists contribute to technology programs. Again, a robust understanding of the differences between the nature of science and the nature of technology is necessary so that students can be taught to understand what questions science (or technology) can and cannot answer.

International trends around the introduction of STS and Socio-Scientific Issues (SSI) require teachers who are confident in knowing what the science is, what the technology is, and their impact on society and social issues. Integrated approaches to STEM similarly require teachers to have an understanding of each of these disciplines and the interactions between them. These developments can engage school students and contribute to developing their understandings in and about science. However, they add complexity to science teaching and learning and teacher education in science.

An essential part of teacher education in preparing generalist primary teachers and specialist secondary teachers is to expand preservice teachers' understanding of the nature of science and the nature of technology. In doing so, it is important that the similarities and differences between science and technology are explored. Focusing on the nature of science (and comparing it with the nature of technology) has the potential to expand both preservice and in-service teachers' concepts of science as well as enhance their confidence to engage with their students and also with a variety of science resources.

Conclusion

Given the traditional separation of science and technology as distinct school disciplines, supporting both preservice and in-service teachers to consider the nature of both science and technology will require deliberate intervention. Finding teacher educators who themselves have a robust understanding of the similarities and differences between science and technology – and what this means for science education – remains a significant challenge.

Cross-References

- ▶ Science, Technology and Society (STS)
- ▶ Science, Technology, Engineering, and Maths (STEM)
- ▶ Socioscientific Issues
- ▶ Technology Education and Science Education

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Science Books

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Books have a long-standing high profile position in science education. It is hard to pin down precisely whether they have any significant educational impact. What is discernible is that they have impact ascribed to them, with scientists frequently referring to the inspirational power of the popular science books (and science fiction) they read as children. Books for adults are also often cited in terms of the public understanding of science and/or political support for science funding.

Overviews of the histories and ideologies of popular science aimed at adults are available elsewhere, so this entry will focus on some of the history and diversity of science books for young people. Most of the examples sit within the 7–11 years age range, largely because this is the age that children's popular science books are produced for. What might be defined as a children's science book will always be reasonably open as we might unpack any of the terms *children's*, *science*, or *book*. Indeed, the books themselves may help articulate the boundaries around such ideas.

Instructive and Amusing

For all that "edu-tainment" is seen as a new term, Arabella Buckley's 1879 *Fairy-Land of Science* is a classic example of the genre. Aiming to cash in on the Victorian mania for fairies, she cloaked the science in the language of fairy stories; her fairies were the forces of magnetism or gravity, with a message that the wonders of science were not only parallel to but could surpass the wonders of fairyland. A more explicitly masculine attempt to similarly apply narrative can be seen in *Peter Parley's Wonders of the Earth, Sea and Sky,* a "thrilling" nature of geology, geography, and meteorology popular in middle-class homes from its publication in 1837. The use of such fantasy and/or travel narratives is still applied today, taking nonfiction readers to semi-fantastical worlds constructed from scientific ideas. Such books might shrink a character so they are small enough to play with atoms or travel fast enough to explore relativity. (Joanna Cole's *Magic School Bus* series and Russell Stannard's *Uncle Albert* books are two popular recent examples.)

A common trait of nineteenth-century children's publishing that is less readily tracked today is an overt connection between studying nature and learning about God. Books would often invoke a sense of wonder by presenting science as a way to learn more about God's creation. In the contemporary scene, the glossier end of children's nonfiction – e.g., *Eyewitness* books – provides a good example of a similar, albeit less religious, appeal to wonder. Full of lavish color photography, the typography of such books is perhaps comparable to glossy magazines such as *Vogue* or *National Geographic*. In contrast, cheaper books such as *Horrible Science* and *Grossology*, which owe more to the aesthetics of *Beano* or *Nickelodeon*, are more likely to appeal to a perceived sense that young people enjoy scatological humor. This does not mean they lack an appeal to wonder; it is just a different style of fascinating they are appealing to, with perhaps less mainstream appeal. Indeed, the idea that only the childish would find this interesting (and that it is slightly taboo in adult life) is perhaps part of the appeal, as young people's media increasingly defines itself via an othering of or from adult life. Although books applying a less glossy aesthetic may also laugh at the pomposity of adult science life, they can also be very reverent towards scientific expertise (see Bell 2008).

Shopping for Science

Books sit in an interesting position economically and socially compared to much other public-orientated science communication. There is an upfront cost, compared to free at the point of click sites such as Wikipedia, or a museum or television show which might be funded by public, charitable, or advertising bodies. Reading a book also implies some time, although without much commitment. Whereas a degree course in a science subject takes significant time and money; a book – especially since the advent of paperbacks – is relatively cheap and portable, easy to keep in a pocket, and dip into around the rest of the day. This, in turn, arguably has an impact on the relationships they may assume with readers and the relationships between science and a public they may help produce.

To Fyfe and Lightman (2007), the idea that the popular science consumer may shop for science puts them in a relative position of power with respect to science. Rather than simply being talked down to – as one might imagine the traditional model for the public understanding of science – the consumption of popular science in a marketplace allows people some degree of choice. Such analysis, however, is based on a rather uncritical view of consumer power. For child consumers of science in particular, it is worth noting that although there are increasing numbers of science books pitched at the pocket money market (compared to glossier books designed to be given as gifts or school prizes), it is possible to argue that children's media are never really owned by the child, rather it is a matter of what adult authors, librarians, parents, and teachers think the child would (or should) enjoy (c.f. Buckingham 1995). It is also worth noting that when it comes to children's science publishing, many books are connected to formal learning, even carrying logos of government education. Such science books are often associated with the "topping up" of the education of middle-class children and, for a host of economic, social, and cultural reasons, are more likely to be used by a privileged few. Their role in supporting formal education might also mean they act as an encroachment of school life on more domestic "play" time.

Interaction

It is notable that the book is a rather individualistic way to consume science, compared to the more group-based experiences of schooling, television, or museum visits. Still, it is worth remembering that books always sit in a social network. For example, children's reference books stay around for decades after they might otherwise do, due to use as school prizes. Also, recent years have seen a rise in popular science book clubs (including those for children who used to judge the Royal Society's children's book prize) as well as authors turning to online social media in ways that not only promote their works and interact with readers but allow readers to interact with one another.

The chief form of interaction offered by children's science books is with the physical, not social, world. In some contrast to the literary/fantastical experiences referred to earlier, many science books promote a very hands-on way of learning science. Indeed, children's science books in particular are striking in their attempts to transcend the traditions of a book form. The more complex examples include stickers to move around (e.g., of partly digested food around a diagram of the gut or magnets hanging from the spine or embedded in pages), and the field of nonfiction pop-up books is flourishing. More simply, there is also a long tradition of books with instructions on how to perform "experiments" – actually demonstrations of known phenomena, they are not experimental – of which John Henry Pepper's *Boy's Playbook of Science*, first published in 1860, is an iconic example (see Secord 2002, for an excellent description to this). Books which play on the empirical associations of scientific work did not end with the *Playbook*. This is perhaps most noticeable in the US market, where instruction manuals for science fair activities dominate the children's science shelves. Still, arguably this is more activity than interactivity. If anything, it is largely a rather conservative form, sometimes dressing up fixed, stabilized, and reasonably old science as if it was fresh and young, but rarely offering anything new, or the opportunity for young people to creatively make something entirely new themselves.

Children's science books are a reasonably diverse field. There are trends as sketched here – of interactivity, reverence to scientific authority, and careful application of fiction for expeditionary purposes – but no tight hallmarks or standout literature in the field. It is common to end such pieces with a general open-ended statement about how the field is always changing and who knows what will happen next. However, despite being aimed at young people and about the supposedly ever changing field of scientific research, another characteristic of children's science books is that they tend to be rather conservative, often rooted in the science (and images of childhood) of at least a generation before the intended audience. It would be nice to think future authors and editors will find it in themselves to be a bit more innovative, but whether or not this happens remains to be seen.

Cross-References

- ► Print Media
- ► Science Fiction

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Science Circus

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The circus proper has a great antiquity. The word derives from the ancient Greek *krikos*, which became, by an inversion, *kirkos* and thence the Roman *circus*. A circus is traditionally defined by its central ring in which performances take place. However, in recent years, it has come to mean almost any spectacular display, such as the American "barnstorming" flying circuses of the 1920s.

Travelling shows are as old as civilization. The first travelling performers probably appeared at the same time as the first villages and towns. Ancient Rome enjoyed its histrions, usually freed slaves who went about entertaining crowds with storytelling, music, songs, juggling, and acrobatics – what, today, we would call busking. In the Middle Ages, minstrels and jongleurs travelled between European towns fulfilling the same role. Miracle plays, in which religious scenes were enacted for delighted crowds, were also a feature of the Middle Ages. First an initiative of the people, they were later taken over by the guilds, each of which had developed its own play. Later, the plays were staged on movable carts and taken around so that more people could experience the wonder and the message. All of these forms were able to present secular, political, and religious information wrapped up as entertainment.

In the eighteenth and nineteenth centuries, and particularly in the southern states of America, travelling medicine shows flourished. While not exactly about science, more about snake oil miracle cures, there was a clear perception that placing a product in the enjoyable context of entertainment created a positive attitude toward the product, resulting in increased sales.

Among the first genuine travelling science shows – in this case the applied science of agriculture – was the Canadian *Better Farming Train*. Agricultural fairs, in which exhibits were assembled in one place to which farmers travelled, were a feature of the Canadian scene from 1894. As the distances involved were a disincentive to travel, in 1914 *Better Farming Trains* began to carry agricultural innovation by rail to farmers in rural Saskatchewan. Hundreds of thousands of people were educated and entertained between 1914 and 1922, when the program was discontinued.

Two years later, in 1924, Australia got its own *Better Farming Train*. It was based in Victoria, and like its Canadian counterpart, it carried pigs, cows, poultry, bees, dairy utensils, potatoes, bacon, tobacco, manure, fodder and pasture samples, and a range of expert lecturers. Between 1924 and 1935 it made 40 trips to ten regional centers. Lectures and demonstrations of infant welfare, cooking, and sewing were offered. The train served as an agricultural school, an experimental farm on wheels, and a chance for a day out for all the family.

While none of the above is a circus in the accepted sense of the word, they share the concept that the delivery of a message accompanied by entertainment is more effective than a message delivered on its own. The success of the *Better Farming Trains* was due, in part, to the fact that Canada and Australia were, at that time, large and relatively undeveloped countries with sparse up-country populations who found it difficult to journey to the cities.

One of the traditional values of the orthodox travelling circus is teamwork. Everyone lends a hand at the various tasks necessary to get a show ready. Erecting the tent, the “Big Top,” is a task that requires everyone’s muscles. The high-flying trapeze artist may be found later selling popcorn and ice cream to the public. The clowns may lend a hand cleaning up after the elephant.

In Australia, in 1986, a large van left Canberra to journey to Goulburn, about 80 km distant. It carried Dr. Mike Gore, some demountable science exhibits, four keen science students, and the germ of an idea. The idea was for a travelling science circus that would cross the length and breadth of Australia, bringing science to remote rural communities. It was a spin-off of Questacon – the Australian National Science Centre that started its embryonic life in the backroom of the physics department of the Australian National University (ANU), grew up in a disused primary school, and came to maturity as a major national institution. Gore was the first director, and the word *National* in the title caused him to grapple with the problem of reaching out to all Australians, not just the local region. With support from Shell Australia, support that continues to the present day, the Shell Questacon ANU Science Circus was born.

For 2 years the Questacon Science Circus was served by selected students from ANU who had been trained as explainers. With Questacon’s transformation into the national center, the decision was made to select a more nationally representative circus team. In 1987, therefore, the ANU and the center established a 1-year graduate certificate in science communication, the first of its kind in Australia and, probably, the world. Competition for places was strong as scholarships were (and still are) awarded to successful applicants. In 1991, the certificate was upgraded to a graduate diploma and in 2012 to a masters degree.

The circus is an institution in which the scholars undertake coursework at the ANU and develop a wide range of skills when on the road. These skills range from learning to present science shows live at schools and other venues, mastering the techniques of educational radio on school of the air, loading, safely, a giant articulated truck with exhibits, acting as floor managers when the circus sets up in show grounds, and becoming exhibit repairers to staffing the circus shop. No task is too menial, and while there are no elephants to clean up after, there are often over excited children!

The primary function of the circus is thus to take science and present it to the people of

Australia, especially the indigenous people, to show that it is both relevant to their lives and a stimulating and enjoyable enterprise. A secondary object is to let a number of gifted and confident young scientists advance their own development with the support of ANU and Questacon. The skills they acquire with the circus and its rapidly growing reputation are such as to make them much sought after in Australia and overseas.

There are very few science circuses. The Canadian *Super Scientific Circus* has been operating since 1994. In its own words, it makes *science fun and funny, using amazing and amusing magic tricks to create visual images for scientific concepts*. While it does not go on the road, it can be booked into theaters, performing arts centers, state fairs, schools, libraries, museums, and science centers. The author understands that it supercedes an earlier model in Ontario that was discontinued.

The success of the science circus in Australia is remarkable and it has won several prestigious awards. In particular, the association between the National Science Centre, the National University, and Shell, extending now over 26 years, has been highly commended. It is, however, worthwhile mentioning two aspects that, more than anything else in the opinion of the author, have led to this success. The first is the scholars themselves. The first team comprised only 8; in 2012 there are 16. They are uniformly young, intelligent, enthusiastic, and energetic. They stay with the circus for 1 year only and then are replaced by a new crop. Enthusiasm and innovation are thus renewed annually; each year a brand new team is sent out to schools and communities to carry the message of science.

The second reason is the accident of geography. Australia is huge (7.7 million square kilometers) with only 22 million people, 12.5 million of whom live in the five largest cities. The remaining ten million are spread across the country and make rare trips to the big metropolises. These are the clients of the circus, which travels thousands of kilometers each year. In England and much of Europe, a major city is rarely more than a short rail trip away. A science circus along Questacon lines would scarcely be viable although more local and smaller travelling shows have been successful. There are, however, other similarly large countries that might benefit, as experience in Canada has shown. Recent trials in South Africa have shown that a travelling science circus can be successful there, and a Cape to Sahara Science Circus is being considered.

Cross-References

- ▶ Learning Science in Informal Contexts
- ▶ Science Community Outreach

Science Communication

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Science communication has been described as a process by which the scientific culture and its knowledge become incorporated into the common culture. This broad definition encompasses a variety of communication styles which may be envisaged as being distributed across a continuum. On this continuum, simple one-way communication of science is at one end, with many who term themselves *science communicators* engaged in one-way activity. *Science journalism* is in this category; it also includes informative articles in the press, screening a television documentary, placing science on the Internet, or presenting a new exhibition in a science center. There is clearly no expectation by the writers, designers, and producers that they will engage in two-way communication, but rather that they are *transmitting* information to whatever audience is willing to listen, play, read, or watch. One-way communication of science also promotes science careers and the need to improve the poor science performance of many school students. Many aspects of science education, with its prescribed learning outcomes, fall into this part of the continuum. It is not, however, the only or perhaps the ideal way to communicate science.

In the 1980s, the movement known as the *Public Understanding of Science* (PUS) became concerned for public scientific literacy. Efforts were made to improve public education in science, assuming a deficit in public knowledge which required to be filled. The assumption was that increased knowledge of science would result in increased acceptance of science. The PUS movement prompted the rise of science centers, festivals, and so on, all aimed at informing an uninformed public. The development of science performance skills in these informal learning arenas has given rise to a narrower definition of science communication as "the use of appropriate skills, media, activities, and dialogue to produce one or more of the following personal responses to science (the AEIOU vowel analogy): Awareness, Enjoyment, Interest, Opinion-forming, and Understanding" (Burns et al. 2003, p. 191).

The PUS movement of the 1980s also gave rise to science communication as an academic discipline. In the 1990s, a number of tertiary programs in science communication was developed under the umbrella of science faculties. This was a marked change from courses in science journalism taught by communication departments. Since the 1990s, science communication as a discipline has constantly been modified in the light of new perceptions of what it means to communicate science. What is now considered to be the ideal mode of communication has shifted from one-way transmission to some form of two-way, participatory practice. This therefore represents the other end of the continuum – a process of knowledge sharing and knowledge building that incorporates dialogue and consensus, decision-making, and policy formulation. The contribution of indigenous science is part of this knowledge-sharing approach.

Definitions of science communication which deal with diffusion of expert knowledge, or the media as the information source, do not incorporate this broader vision of what it means to communicate science. It is now widely recognized that knowledge *deficits* are not restricted to the general public or to *nonscientists*: they apply to all participatory groups, including *experts* (Stocklmayer and Bryant 2012).

The term *public engagement* has been coined to replace PUS. It acknowledges that the communication of science with a broad public is important, especially when concerned with issues of democracy. It is notable that notions of the nature of science are not the same in the public domain as they may (still) be in the classroom. Ideas about uncertainty of science, the views of science as an unchallenged authority or as a given body of knowledge, have all shifted in recent times as the concept of authority itself has altered. The rhetoric of public engagement has led to increasing attention being given to ways of involving the general public in scientific issues. This was summarized by the UK Research Councils (2002, p. 3):

> With the increasing recognition that dialogue and multiple inputs are crucial factors in underpinning sound decision-making in science, it has become accepted that two-way communication is a more robust way to address [this].

Research in science communication is therefore broad-based, since effective engagement requires contextual understanding of issues such as appropriate framing, belief, knowledge, cultural influences, and perceptions of risk. Of necessity, such research incorporates multidisciplinary approaches drawn from the sciences, the arts, and the humanities.

Cross-References

- ▶ Public Communication of Science and Technology
- ▶ Public Engagement in Science

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Science Community Outreach

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Keywords

Community based; Identities; Role models

The mantra of "science is all around you" echoes through a multitude of classrooms and textbooks. However, as our youth step out of their schools every afternoon, there is frequently very little evidence of the value placed by society on science in their communities, and little connection is made between the science curriculum learned at school and student identities as they participate in their everyday life activities. Community-based science programs bring science to the neighborhoods in which the youth live and allow community members access to a wide range of scientific processes in familiar settings. They can be powerful experiences for all if they are well designed and situated.

Science practitioners, ranging from gardeners, farmers, and chefs to engineers and doctors, have science concepts and skills embedded in their daily tasks. When communities are able to highlight the relationship between these activities and science, community members who participate in such events stand to gain an appreciation of the value of science as well as the diversity of scientific understandings and their applications. Further, the fact that community members are involved in such presentations points to the feasibility of local people enjoying a relationship with science. The power of local role models can be great. Finally, because parents, particularly mothers, can engage in such programs, it is extremely valuable from a science education standpoint, since their influence on their sons' and daughters' academic interests is known to be strong.

An illustrative example of a science-related community-based program is the Contact Science program, launched in Texas in 2010 with the goal of bringing a set of diverse, engaging, and interactive science experiences to various communities in the Dallas Fort Worth Metroplex. It is the brainchild of Russell Hulse, Nobel Laureate in Physics, located at the University of Texas at Dallas. At the heart of the program were the design, construction, and placement of adventure stations around various themes in public libraries. These stations functioned as miniature lab benches and had real science tools as part of them. For example, the Electrical Adventures station included an oscilloscope and all the various components to allow for a wide range of experimentation with electricity; the Microworld Adventures Station included a high-end light microscope, as well as a "scope on a rope" that allowed users to look at a monitor to get close-up views of their skin, a leaf, clothing, or anything of interest. Each station had a computer guide with step-by-step experiments for the user to start off with, or the user could play with the components independently and truly experiment as they wished. Each station was designed so that it was convenient for the libraries to rotate the theme and materials every few months. The bench or base unit would stay at the library, but the oscilloscope and other equipment could be removed and easily driven over to a different library. In this way a group of libraries could get a new exhibit every few months. The key strategies used by Contact Science were, firstly, partnering with a system that was already designed to serve local communities, i.e., public libraries, and, secondly, focusing program experiences around authentic scientific tools. To this latter end, staff at the University of Texas at Dallas worked with the Science Museum of Minnesota, an institution that designs and fabricates exhibits for museums around the country. A good match was perceived between some of the lab bench-like exhibits that were on the museum floor and the nature of science activities to be placed in communities around the university. A productive working relationship emerged with Contact Science, with the collaborative adaptation of three of the museum's existing small, interactive exhibits for use in the community-based pilot program. Further, since the program was housed in a university, there was a natural partnership with university resources, particularly access to university student volunteers who would assist in providing additional programming, such as robotics workshops that were also held at these libraries, as well as to students and faculty who were interested in extending the reach of the adventure stations by adding demonstrations and facilitation. Involvement of these three different institutions (library, university, and museum) required considerable learning and working around the varying cultures of these spaces. However, the effects of using the resources present in each institution collaboratively in bringing thoughtful science educational experiences to communities made this a worthwhile effort.

Communities that are able to identify their science-rich resources and create spaces for people to come together to participate in various science-related activities stand to gain a population who can identify the ways in which science is relevant, interesting, and useful. Community spaces and groups such as public libraries, boys' and girls' clubs, girls' scout troops, and recreation centers have the advantage of a pattern of frequent and repeat visitation, unlike informal learning spaces such as museums. This allows for repeated engagement in science programs housed in these spaces, in contrast to the "hit and run" science that frequently occurs in informal learning spaces to which regular visits tend not to occur. Partnerships between institutions, such as museums, research centers, community spaces, and schools, can allow for the design of relevant, conceptually rich, tool-based science experiences designed to incorporate multiple entry points. Involvement by community role models, such as university and high school students and other professionals living in the community who volunteer as explainers or in other ways interact with users, can augment the power of such community-based science outreach experiences.

Cross-References

- ▶ Citizen Science
- ▶ Hobbies
- ▶ Lifelong Learning
- ▶ Science Circus
- ▶ Science Museum Outreach

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Science Curricula and Indigenous Knowledge

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Keywords

Science Education in the Non-West

Curriculum can be thought of as what is required to be taught, its scope and sequence. This is usually in the form of documentation prepared by an educational authority to be used in schools and colleges under its auspices. In recent times some of this work has been done at a national level by agreement with state, provincial, and local educational authorities (where they exist) which may then modify and enact the curriculum within their domains. In some cases the curriculum may be prepared by recognized external agencies such as the International Baccalaureate. The curriculum differs from individual teacher's or school-based programs which are interpretations of the curriculum for individual school or classroom contexts. Universities usually prepare autonomous curricula although there are usually processes nationally and internationally to ensure comparability.

A related interpretation of curriculum refers to curriculum resources, a classroom resource which may have been developed by the educational authority, by an interested organization, or often by groups of teachers to implement the curriculum. Curriculum resources are usually considered to be a link between the curriculum and the classroom pedagogy; however, resources may be developed which are not based on the curriculum or reflect a particular interpretation of its meaning. Textbooks can also be considered as curriculum resources which should reflect the curriculum.

There has been some discussion of the inclusion of indigenous knowledge in the science curriculum in recent times, although previously there have been instances of the inclusion of indigenous knowledge in some ways, most frequently in textbooks. Critiques of this portrayal have focused on stereotypes which denigrate indigenous peoples and their knowledges. There has been advocacy for the inclusion of indigenous science in mainstream science courses primarily since the 1990s, and terminologies such as multicultural science and multi-science have been used by the advocates. This has been undertaken by both indigenous and non-indigenous scholars (including Aikenhead, Jegede, George, Kawagley, Cajete, Snively and Corsiglia, Stanley and Brickhouse, Cobern, Pomeroy, and Ogawa). Criticism of these approaches has been mainly made by a group of science philosophers who make a distinction between the universality of Western modern science as core science and the lesser position of indigenous knowledge and indigenous sciences. However, this argument has in some ways been circumvented in some countries where educational authorities have mandated the inclusion of "indigenous perspectives" across the curriculum, including the subject science. Other arguments include approaches to redefine Western modern science to be inclusive of indigenous knowledge (particularly approaches to African science).

Science and Indigenous Knowledge

Since the Rio Earth Summit in 1992, there has been an increasing recognition by some professional scientists of the role of indigenous knowledge, particularly in areas involving land management and the environment. At the UNESCO World Conference on Science for the Twenty-First Century, in 1999, there was a call for a wider use and support for traditional forms of learning and knowledge, as well as cooperation between holders of traditional knowledge and scientists to explore the relationships between different knowledge systems and to foster interlinkages of mutual benefit. As a consequence, in 2002 the International Council for Science (ICSU) prepared a report on science and traditional knowledge. It was pointed out by a subcommittee that traditional knowledge was informing science, particularly in nature management. They recommended that the ISCU and member nations should sustain traditional knowledge systems through active support to the societies that are keepers and developers of this knowledge, promote training to better equip young scientists and indigenous people to carry out research on traditional knowledge, and promote and develop research to better appreciate traditional knowledge. Just prior to the Rio+20 UNESCO conference in June 2012, an ICSU session on indigenous knowledge noted that indigenous and traditional knowledge has gained increasing recognition as an essential building block for global sustainability, as well as a change in relationship between scientists and indigenous knowledge holders. A shift away from the notion of scientific validation of extraneous knowledge and its integration into science was leading toward an approach anchored in the codesign of research and the coproduction of new knowledge to address complex emerging challenges. Diverse knowledge systems were becoming more valued because of the benefit of place-based knowledge systems of heightened local relevance.

Areas of knowledge production which have seen the interaction of Western scientists and their indigenous counterparts include (to use their Western names) ethnobotany and ethnobiology, archeoastronomy, and agriculture. These interactions have seen the exchange of knowledge by both groups of people in a variety of ways, including elders from both groups. This exchange is limited to fields of knowledge where some similarity occurs and varies because of the place-based nature of indigenous knowledge. Often the knowledge is referred to as indigenous science or a way of knowing or, if it is more specifically environmental, as traditional environmental or ecological knowledge (TEK). Occasionally the location of the knowledge will be specified, such as Maori environmental knowledge or the Yupiaq way of knowing. Thus, there is an attempt by some professional Western scientists to broaden the definition of science to become more inclusive of place-based indigenous sciences.

Some researchers in science studies have considered that although indigenous knowledges had lacked "the same authority and credibility as science because their localness restricts them to the social and cultural circumstances of their production" (Watson-Verran and Turnbull 1995, p. 116), there was now an explicit focus on the local as an implicit basis of scientific knowledge. It has been suggested that the ways of understanding the natural world that have been produced by different cultures and at different times should be compared on an equal footing. Such epistemological relativism was rejected by other science studies researchers. Although Western science could be considered to be a localized knowledge system, as are other ethnosciences, the notion that they are equally defensible was rejected. The standpoint approach was that different cultures' knowledge systems have different resources and limitations for producing knowledge.

Others who were researching indigenous knowledge and education considered that it was possible to produce a transformative science which would highlight the differences and complementarities between Western science and indigenous ways of knowing. Some wished to initiate "a conversation resulting in a critique of Western science that leads to a reconceptualization of the Western scientific project around issues of multiple ways of seeing, justice, power, and community" (Semali and Kincheloe 1999, p. 45). Their idea of an indigenously informed transformative science is not simply an addition of knowledge but "challenges the epistemological foundations of ethnoknowledge known simply as science" (p. 45). They also suggested that indigenous knowledge could transform education and that its inclusion in the curriculum leads to a needed interaction with "difference" for Westerners, leading to a heightened consciousness which is more empowering than "a narrow focus on homogeneous cultural traditions" (Semali and Kincheloe 1999, p. 47).

Science Education and Indigenous Knowledge: Multicultural Science Education

In the past twenty-five years, there has been much research in education in general and in science education in particular into indigenous ways of knowing. Multicultural science educators questioned whether the Western knowledge base was appropriate or culturally biased, specifically questions such as: "Whose culture are we teaching? Whose knowledge is of most worth? Who benefits and who is harmed by current approaches to curricula?" (Stanley and Brickhouse 1994, p. 387). It was suggested that holding a universalist position with regard to scientific knowledge gave a feeling of omniscience to scientific knowledge and has led to the destruction of other knowledge systems regarded as inferior by Western standards. What was advocated was a community of learners with "the capacity to generate and consider various possibilities for understanding and determining knowledge" (Stanley and Brickhouse 1994, p. 394). This was seen to lead to a science education from multiple perspectives rather than one perspective, although these other perspectives should not be given equal weight in the curriculum. Later, concern was expressed that universalist Western modern science could be taught as if it was neither controversial nor problematical and that multicultural education introduced students to new ways of thinking about the natural world helping them to understand not only other ways of thinking but also some of the fundamental understanding of Western ways of thinking.

The relationship between Western modern science and indigenous science, particularly traditional ecological knowledge, has been discussed in the context of science education. The local nature of traditional ecological knowledge and its transmission were considered as an oral narrative, and its place related to sustainable development. The relativist nature of indigenous science is a reflection of its local applicability, in contrast to the universalism of Western modern science. The spiritual base of traditional ecological knowledge is also seen as an impediment for it being considered as science by many Western scientists. What seems to be forgotten is that most indigenous sciences are accumulations of observations, refined over time, what is referred to often as "the wisdom of the elders." Other science educators suggested that Western science could be defined with sufficient clarity so as to maintain a coherent boundary for the practical purposes of school science curriculum, using the standard account for science, and that the boundary would exclude indigenous knowledge as well as other domains of knowledge. It was suggested that it would be better considered as a different kind of knowledge, valued for its own merits. From such a position it could maintain its independence from which it could critique the practices of science rather than be co-opted into a universalist science. Some indigenous science educators have seen the inclusion of indigenous education as being important, particularly in providing a more culturally relevant frame of reference for teaching science to indigenous students. Others, noting that teaching of science is mostly by Western teachers, were concerned that the treatment of indigenous knowledge would be oversimplified and essentialized to the point of becoming a caricature of its reality.

The incommensurability of multiculturalism and universalism was examined in the context of traditional ecological knowledge and Western science. It was pointed out that "the reduction of local contexts [of TEK] to scientific praxis is inherent to the transcendent nature of scientific knowledge and includes a loss of local heterogeneity, dynamic, and plurality; and transcendent scientific knowledge is useless unless local contexts are reduced to the conditions of scientific laboratories rather than remaining contexts in their own right" (van Eijck and Roth 2007, p. 18). It was concluded that traditional ecological knowledge and Western science were different but were useful in specific local contexts and that traditional ecological knowledge could relate to students learning to solve local problems.

On the other hand, there has been a negative response from a group of Western scientific philosophers critical of multicultural science, including traditional and indigenous sciences, and its influence on the science curriculum. The universalist position advocated mainstream Western science and was critical of multicultural science, particularly a form referred to as "robust" or "noninterventionist multiculturalism." Robust multicultural science was considered by these critics to be relativist and promoting equally validity with universalist Western science. A version of multicultural science termed "epistemic multiculturalism" was also considered incompatible with universalist science. Here multiculturalists were criticized in particular for attempting to broaden the notion of science to include ethnosciences, traditional ecological knowledge, and indigenous knowledges. In considering whether indigenous knowledge or traditional ecological knowledge should be included in the school science curriculum, a version termed "limited compatibilism" was proposed. By this was meant whether there were sufficient similarities between the indigenous knowledge and Western science, normally judged against Western science.

What is notable in the discussions of both the scientists and the science educators who are involved is the emphasis of place-based and local knowledge in the indigenous sciences and traditional ecological knowledge. How to implement this sense of the local through the curriculum and then into pedagogy is one of the difficulties being addressed by some multicultural science educators.

Science Curricula and Indigenous Perspectives

In the later part of the twentieth century, many countries reappraised their school curricula and developed national goals for education. In several of the settler states – those countries which had been colonized particularly by European countries but which had since become independent – the national goals included references to the original indigenous inhabitants. This occurred both in countries with a majority population of mostly European origin such as Australia and Canada and in those with a native majority such as South Africa. An outline of the Australian experience in endorsing indigenous perspectives is summarized here.

The first attempt to develop national goals for school education in Australia was at the end of the 1980s and was called the Hobart Declaration. Although education in Australia is controlled at the state or territory level of government, the federal (national) government is concerned with issues of quality of education across the nation. In a national project funded by the Ministerial Council for Education ministers, a series of agreed goals of education – the Hobart Declaration – was reached. These were to inform development of national curriculum across the eight identified curriculum areas, including science, as well as identifying a number of cross-curriculum perspectives. Item 8 read: "To provide students with an understanding and respect for our cultural heritage including the particular cultural background of Aboriginal and ethnic groups." The reference to Aboriginal culture was interpreted as applying in the teaching and learning of science and needed to become evident in science curricula developed nationally; it became commonly referred to as the "indigenous perspective."

The Hobart Declaration has been updated on two occasions, as the Adelaide Declaration (1999) and the Melbourne Declaration (2008). The Melbourne Declaration included providing students with an understanding and respect for their cultural heritage including the particular cultural background of Aboriginal and ethnic groups and giving all students the opportunity to access indigenous content where relevant. As well, within the goal of promoting equity and excellence, it included ensuring that schools build on local cultural knowledge and experience of indigenous students as a foundation for learning and work in partnership with local communities on all aspects of the schooling process, including to promote high expectations for the learning outcomes of indigenous students. This represents a shift through the declarations from solely consideration of indigenous knowledge to ensuring inclusion of indigenous peoples in all aspects of the schooling process.

There have been attempts to develop a national curriculum including science in Australia since the 1990s, and although its implementation by the various states and territories has been varied, these attempts have influenced the science curriculum in all jurisdictions. Its latest form is the National Curriculum: Science released by the Australian Curriculum Assessment and Reporting Agency in 2011, which covers the years from Foundation to Year 10. A cross-curriculum priority in the national curriculum, including science, is termed "Aboriginal and Torres Strait Islander histories and culture," although it is commonly referred to as the indigenous perspective. Indigenous perspectives in the science curriculum are incorporated as possible elaborations in the Science as a Human Endeavour strand rather than the Science Understanding strand. This has been seen by some commentators as continuing to treat indigenous knowledge as inferior to Western science knowledge. Some science educators have suggested that the discussion regarding the nexus between indigenous science and Western science could be treated as relating to the nature of science, which is implicitly within the realm of Science as a Human Endeavour strand in the Australian curriculum.

Similar processes incorporating indigenous perspectives into the science curriculum can be noted in the recent curriculum development in a number of countries, particularly Australia, New Zealand, Canada, and South Africa. Thus, it can be seen that the imperative to be inclusive of indigenous culture and knowledge has been taken up by curriculum authorities.

It has been advocated that indigenous science should be included in the science curriculum, for a number of reasons. Indigenous science could be seen as part of the way we can understand the world. Secondly, indigenous science could tell us something about Western science and science education. Finally, it was a way of achieving reconciliation between indigenous and non-indigenous peoples and a vehicle for social justice. Earlier, indigenous perspectives were perceived primarily as impacting on non-indigenous students. However, as seen in the commentary on the Melbourne Declaration, they have evolved to impact on the education of indigenous students. This included trying to reconnect indigenous learners with their roots and developing cultural citizenship, as well as expanding our knowledge base in a knowledge society.

The new South African science curriculum prescribes the inclusion of indigenous knowledge, allowing for localized content and accommodating different ways of learning although it is not always clear what this means. In common with curriculum documents in other countries, what is often described as indigenous knowledge are fragments which fit with Western science, compatible with the notions of oversimplification, caricature, and essentializing treatments suggested by some science educators but perhaps a pragmatic implementation of limited compatibilism also. However, there has been a call for indigenous knowledge to be included in Western science in several parts of Africa by a number of African science educators, both indigenous and non-indigenous (including Jegede, Ogunniyi, Semali, Okebukola, Gitari, Keane, and Malcolm), a call which resonates with that made by African scientists as well.

The development of a Maori science curriculum, *Putaiao*, in Aotearoa, New Zealand, in the 1990s, has offered a precedent for similar curriculum development elsewhere. In writing the Maori science curriculum, the Western science curriculum was reconstructed to match up with Maori understandings of the world; much of the Planet Earth and Beyond strand, in the Maori version, has gone into the Biological World strand, which was renamed *Mataora*. What is important for Maori it that this represents the joining of *Papatuanuku* (earth) with the rest of living things (as defined through science). However, there are a number of conditions imposed which limited the accessibility of students to the curriculum. Firstly, the document is written in Maori, for students who are learning through the medium of Maori. Secondly, there were issues regarding language at two levels. At one level there were differences which are apparent with the syntax construction between native speakers and second language learners of Maori. Then there were issues of a “standardized” Maori language in a country made up of various tribal groups with differing dialects.

From time to time indigenous influences on science curriculum have been put aside. In Hawaii a science standard called *Malama I Ka ‘Aina* was adopted in 1994. It incorporated an awareness of Native Hawaiian phenomena and supported culturally responsive, place-based curriculum. However, it was removed in 2005 on the recommendation by out-of-state consultants because it was seen as being too limited to Hawaiian culture, suggesting the political challenges to forms of multicultural science education were not completely aligned with mainstream perspectives.

There appears to have been limited critique of the role of the education authorities in implementing indigenous perspectives. One criticism would come about from the assumption that indigenous and Western knowledges run parallel, when they have been shown by a number of scholars that they have different characteristics. A second, related criticism would apply because the authorities subdivide indigenous knowledge according to the Western fields of knowledge, including science. As noted about, in school science curricula, there has been a tendency to fit the indigenous perspectives into the Western science curriculum structure. This has led to a simplification of the indigenous knowledge to the point of caricature.

Conclusion

There have been two approaches to the inclusion of indigenous knowledge in the school science curriculum. The first of these is by scientists working close to indigenous peoples who see indigenous knowledge as valuable, particularly as local knowledge. One of their strategies is to expand the definition of Western science so that it can include indigenous knowledges in a respectful way. They are supported by a group of multicultural science educators who also wish to be respectful of indigenous students' prior knowledge. The idea of expanding the definition of science and inclusion of indigenous knowledge in the school science curriculum is opposed by some philosophers of science. Separate from this and somewhat preemptive of the work by scientists and science educators is a move by many educational authorities to include indigenous knowledge across the curriculum, often referred to as indigenous perspectives. This includes in the science curriculum although it seems that often it is not clear what an indigenous perspective means. What is becoming clear from science, science studies, and cultural studies in science education is that indigenous knowledge incorporates a local perspective that complements the science one.

Cross-References

- ▶ Indigenous Knowledge Systems and the Nature of Science
- ▶ Indigenous Students
- ▶ Multiculturalism
- ▶ Science Curricula and Indigenous Knowledge
- ▶ Teacher Preparation and Indigenous Students

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Science Departments

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Keywords

Head of department; Secondary science department; Subject department

The science department as a unit within secondary or high schools began to emerge in the mid-nineteenth century. Arising from the increasing differentiation of knowledge that accompanied the Industrial Revolution, the development of departments was intrinsically linked both to the prevailing sociopolitical forces of the time and to the rising status of the academic disciplines. As Layton (1973) notes, prior to the professionalization of science and the development of the department as an organizing feature of secondary schools, science education was heavily influenced by a concern for working from the concrete to the abstract. One of the most influential science educators of the time, Richard Dawes, was concerned that students should initially engage with science through the common things they saw around them and from this interest work toward scientific explanations of phenomena. His efforts were highly successful, to the extent that Dawes took on the role of instructing his teachers, and their apprentice teachers, in both scientific principles and the application of his teaching strategies.

The early rise of the science department is closely linked to the professionalization of science, a movement largely driven by William Whewell and the British Association for the Advancement of Science. Whewell argued that science, as a discipline, should be taught in an abstract form and should serve the goal of "mental training." It was believed that only the upper classes were capable of the "mental training" required by the high-status, abstract, academic disciplines, while the lower classes were only capable of simple, concrete thought. Secondly, the newly professionalized scientists worked to secure status, and hence resources, for themselves and their discipline, especially within universities. Academic disciplines accrued to themselves control over both content and the entry requirements to their discipline. Importantly, the universities were given the power to set entrance examinations, a move that was to have profound implications for teaching and learning in schools.

In order to accommodate the demands being placed on them by the universities, schools began to adopt standardized systems of timetables, lessons, and school subjects. The organization of school subjects reflected the university disciplines. This development began in Britain in the 1850s and was basically completed there in 1917 with the establishment of the School Certificate that defined both content knowledge and the evaluation of that knowledge and established preferred teaching strategies, for university preparatory subjects such as Botany, Physics, and Chemistry. This pattern was repeated across the British Empire and in the United States, where the Committee of Ten also expounded the virtues of "mental training." In schools, these subjects were to be taught by content specialists who could meet the expectations of the examinations. These content specialists were to form the first school subject departments. Science was seen as a specialist activity; hence there was little effort to develop the pedagogical skill of the teachers. Consequently, the role of the department was principally administrative, charged with ensuring that university entrance standards were met. The first modern usage of the term department was in 1905, and by the 1920s, secondary teachers in Western countries were being educated in the university disciplines, a development that reinforced the bonds between the discipline and the department. This strong historical link between the discipline and the subject is an important feature in understanding the function and power of the contemporary school department.

In the first half of the twentieth century, major demographic changes occurred in Western countries, in the form of mass immigration, increasing urbanization, and major changes in child labor laws. The huge increase in the public secondary school population, together with the loss of influence of the "mental training" view of education, profoundly changed the work of the department. While still seen as subject specialists, departments took on an increasing responsibility for pedagogy, supervision, and administration. In the 1950s, academic research began to focus on the potential importance of the department for improving the quality of science education. Research at this time suggested departments should maintain a simultaneous focus on supporting students, while also maintaining links to their associated academic, professional, and school communities. This research focus has developed sporadically over the past half century.

Siskin (1994) has defined four aspects of the school-based subject department that she believes are crucial to the delineation of the subject department in contemporary American high schools. The department, according to Siskin:

> . . . represent[s] a strong boundary in dividing the school . . . provide[s] a primary site for social interaction . . . [is] an administrative unit, [with] considerable discretion over the micro-political decisions affecting what and how teachers teach, and as a knowledge category influences the decisions and shapes the actions of those who inhabit it. (p. 5)

Working from these aspects and reflecting their evolution, science departments possess two concurrent functions within the school: the social and the organizational (Melville and Wallace 2007). The social function is a powerful one; within departments (particularly in high-status subjects such as science) teachers are socialized into what is important in their subject content, how it should be taught, and why it should be taught. This socialization shapes, and is shaped by, teachers who identify themselves primarily as teachers of science. This identification is founded on their university education in the sciences, an understanding of the language of science, and a common view of the place of science in society and education. In terms of professional learning, a shared sense of identity is foundational to the work of effective departments, as it allows teachers to trust the judgment and abilities of their colleagues and be prepared to learn from each other. Trust facilitates access to other's knowledge, for example, about content, pedagogy, and the relation of science to society.

The social function is foundational to the organizational function of departments, for their organizational power lies in the capacity to influence how and what teachers teach. Teachers educated into a discipline will generally replicate the academic traditions of that discipline; this is a principal reason why secondary teachers maintain their own practices in the face of efforts to reform teaching and learning (cf., Carlone 2003). Taken together, the social and organizational functions of departments give them tremendous political power with which to arbitrate their response to reform efforts. The members of a strong department may achieve an organizational consensus about what is important in their subject, with the important caveat that within science, teachers can, and will, disagree about the nature of the discipline and, hence, what constitutes "good" teaching. Such a consensus (if developed) is important for ongoing professional learning, as it allows for the establishment of clear goals for student learning. The establishment of consensus cannot, however, be assumed for departments, and there is always the risk that the consensus may be to not change what has "worked" in the past.

Traditionally within departments, the role of leadership has been the preserve of the officially designated, middle management, head of department (or chair in North America). Aside from the established concern for pedagogy, supervision, and administration, Brundrett and Terrell (2004) note that the role is increasingly perceived as being:

> Moral and . . . political . . . because it involves the creating, organising, managing, monitoring and resolving of value conflicts, where values are defined as concepts of the desirable . . . and power is used to implement some values rather than others. (p. 17)

Within the literature on departments, the notion of teacher leadership is being given increasing prominence. Teacher leaders simultaneously undertake and model their own professional learning, while working to build a culture of collaboration that benefits students. Such leadership requires the capacity of teacher leaders to function effectively across departments as both communities and organizations, for, in doing so, they can influence three key reform areas: to provide leadership in the promotion of teaching and learning of science, to develop learning opportunities, and to establish a capacity for reform (cf., Yager 2005).

Cross-References

- ▶ Communities of Practice
- ▶ History of Science
- ▶ Identity
- ▶ School Environments
- ▶ Secondary Science Teacher Education

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Science Education in Iran

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Keywords

Science Education in the Non-West

Iran's history as one of the oldest empires dates back to the seventh century BCE. Iranians were mainly Zoroastrians and considered themselves Aryan Persians. Over the pre-Islamic period, instruction in reading, writing, mathematics, medicine, and astronomy was accessible to privileged higher social classes. The wars between Arab Moslems and Persians brought the Old Iranian (Persian) Sassanid Empire and its central government to an end in the seventh century CE. The influence of Islam on Iran changed not only the political climate but also cultural worldview of Persians. Islamic teachings such as monotheism, justice, brotherhood, and equality for all human beings have influenced the Iranian mind.

After the arrival of Islam, Iran's history witnessed much social and political upheaval. Historians of Iran mention the tenth and eleventh centuries as the first golden age of scientific and social development (Nasr 2009). Iranian Moslem scientists extended the frontiers of science based on an inductive-deductive approach. Rhazes, Avicenna, Jabir ibn Hayyan, Biruni, and Kharazmi were among the Iranian scientists whose works were translated into Latin during Medieval and Renaissance periods, paving the way for scientists to build modern experimental sciences. The Moghul invasion in the thirteenth century, in contrast, triggered the fall of science in Islam and Iran. During the Shia Safavid period (sixteenth–eighteenth centuries), however, there was a second rise of scientific advancement (Velayati 2007).

Impacts of Social and Cultural Context

The rulers of Iran in the first half of the nineteenth century, after a number of military defeats, concluded that the weaknesses of the country needed to be addressed through the establishment of a modern educational system. Students were dispatched to European universities and the Dar-al-Fonun (polytechnic) was established at home in 1871. The Dar al-Fonun was the first modern college in Iran. At Dar al-Fonun, medicine, pharmacy, military studies, and engineering were taught by European teachers. Modernization of Iran's education system was based on the translation and adoption of Western knowledge and institutions. The use and adaptation of materials and technical and institutional developments without accepting the West's intellectual and cultural system was and still is problematic (Ringer 2013). The question is how to be modern without losing Iranian identity and integrity. Different answers based on different cultural and political directions have been offered for the question. During the Pahlavi dynasty (1926–1979), for instance, modernization followed secularization and centralization of education, with great emphasis placed on Aryan pre-Islamic identity. However after the Islamic revolution of 1979, the centralization continued but the Shia Islamic identity was underscored.

Directions

Education at Dar al-Fonun was elitist, the aim being the education of students for future government employee positions. However, education in the late nineteenth century, when early elementary schools were established, was mainly based on nationalism. The aim was the education of citizens. The discontinuity and lack of proper harmony between preuniversity and university education and the lack of an organic relationship with the work market have influenced science education in Iran. Iran's oil-dependent economy has hindered the attempts to surmount the disharmony. Not only has the governmental oil-reliant economy been a crucial factor in the persistency of the gap between education and the labor market but also a serious barrier to developing a knowledge- and technology-based economy. The two universal directions, preprofessional training and science education for citizens, have affected science curriculum in Iran. Likewise the Iranian Islamic worldview and a different cultural interpretation of science from the West have had a crucial impact. Iranians debate the nature of Islamic science and its relationship to science in general (Golshani 2004).

The orientation of science education in the new national curriculum of Iran is expressed as follows: comprehensive and holistic growth of students based on the assumption that acquiring knowledge in itself is a spiritual attempt that leads to a more profound and teleological understanding of the created universe and consequently to attain monotheistic insight as a component of the "good life" (*Hayat e Tayebeh*). However, in practice, the two following ideological trends are more noticeable: (1) preparation of students for entrance to universities in order for them to find their jobs in science and technology or governmental positions that lead to higher social status and (2) preparing students who do not want to have any profession or job related to science and technology but need to adapt themselves to a society that is increasingly getting dependent to science and technology.

Intended Changes

Since the late nineteenth century and with the expansion of new schools, policy makers and the general public have always paid attention to and facilitated qualitative and quantitative growth in science education**.** Changes in formal science curriculum can be classified roughly into six periods:

First period (late nineteenth century–1942): Prior to the nineteenth century, Iran had no specific aims and content for science curricula. Teachers would organize their teachings based on their own personal views. Mirza Ali Khan-e Moallem in 1911 and Mohammad Tadayon Birjandi in 1912 were the first textbook authors for the 5th and 6th grades. These books promoted the teaching of pure science. In 1912, a system of 6 years of compulsory education followed by another 6 years of non-compulsory education was enacted. Subsequently science curricula which included a list of syllabi for the two 6-year programs were designed, and a series of pedagogic principles were passed by the Ministry of Education. The syllabi contained content differences with respect to gender roles based on traditional Iranian society. Teachers taught content following predetermined principles. Gradually teachers were allowed to choose from a list of government-approved textbooks. In 1930, for the first time, the Ministry of Education published elementary textbooks and 10 years later published textbooks for high schools. These textbooks, called Vezarati (ministerial), were written by a team of university professors and experienced teachers. Although these textbooks were of fine quality and were welcomed by teachers, due to financial difficulties, the government was unable to publish and distribute them throughout the country. Therefore teachers were free to use Vezarati textbooks or pick from other textbooks.

Second period (1943–1967): Due to political and economic disorders caused in part by the Second World War, there was little planning or management of science education by the Ministry of Education during this period. All science curriculum development activities were surrendered to the free market. Although the competitive atmosphere motivated many to do research and develop science curricula, lack of guidance and supervision led to disorder in school science. In1963, Iran's Textbooks Organization was established and became the exclusive agency in charge of publication of textbooks. Dr. Mahmoud Behzad, the first director of the organization and the author of several science textbooks and teacher's guides, improved school science (Mo'tamedi 2012).

Third period (1968–1980): During this period, public compulsory education was increased from 6 to 8 years and the educational system changed to 5 + 3 + 4 model. Science was made compulsory at all grades. The aims of science education broadened and were influenced by science education in the USA. During this period, government political influence increased, and education became more centralized and was expanded. Returning to the practice of earlier periods, teachers were required to implement an official curriculum.

Fourth period (1981–1995): In the early years after the Islamic revolution, due to the heavy content load and teachers complaints, the content volume of science education slightly decreased. Parts of some science textbooks were revised to remove positivistic ideas. All in all the importance of teachers' role in science education and new science teaching methods were highlighted. Teachers who were found to be committed to Islamic teachings were selected to underline the Islamic values. Shortage of qualified science teachers as a result of economic difficulties, caused by the Iraq-Iran war, was noticeable in this period.

Fifth period (1996–2010): During this period, new science textbooks and teacher training curricula stressed constructivist approaches, collaborative learning, hands-on minds-on activities, descriptive evaluation, and content relevance for all grades. The educational material and information and communication technology were used to support teachers and learners. Research was emphasized, and some efforts were directed toward the development of theoretical indigenous science and also science education (Bagheri Noaparst 2011, Golshani 2004).

Sixth period (since 2011): In recent years, Iran has adopted a new philosophy of formal education and a reform of the national curriculum is being planned. Integration among different disciplines, attention to real-life interests, and educating creative and responsible students are among the main concerns. Science education in elementary and lower secondary grades is being redesigned, using a thematic approach with integrated learning activities. Upper high school education is based on separate disciplines. Promoting the professional position of teachers and a decrease in centralization are among the formal plans.

Cross-References

- ▶ Epistemology
- ▶ Humanist Perspectives on Science Education
- ▶ Indigenous Knowledge
- ▶ Values and Indigenous knowledge
- ▶ Worldview

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Science Education in Mainland China

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Keywords

Science Education in the Non-West

Introduction

The last three decades have seen a tremendous transformation of school science education in mainland China in terms of provision and access, curriculum and pedagogy, and assessment. In addition, there has been major transformation in science teacher education. In part these reforms of science education have been in response to international science education trends and reforms which have provided impetus and influence as the Chinese government has continually followed the policy of reform and opening up to the world. And in part the reforms arise from the rapid social changes that have taken place in the realms of Chinese economy, politics, and social life (Wei 2008).

As is the case with schooling in general within mainland China, it is generally recognized that Chinese science education has had little visibility internationally. This is most likely because of the lack of science education research done by Chinese science educators who can publish in major international journals of science education. In this entry, I provide readers with an insider's perspective. First, I give some background by highlighting the historical overview of science education in China. Second, I present a description of recent reforms of school science education reforms in mainland China. Finally I conclude with a summary.

Historical Background

Although modern science first came to China from the West with the Christian missionaries, initially in the late Ming dynasty and then in the late Qing dynasty (Wang 1997), it was in the first part of the twentieth century that the first generation of Chinese scientists who trained in the West grew up and worked in Chinese universities and research institutes (Wang 2002). The following facts clearly show that it was only a twentieth-century phenomenon for modern science and science education to establish themselves in China. The first national university, Peking University, was founded in 1898 by the Qing dynasty government, while the first modern school system was borrowed from the West by patterning from that of Japan in 1904. The first science society, i.e., the Science Society of China, was set up in 1915 by a group of Chinese overseas students studying science and technology in US universities (Wang 2002), and the Academia Sinica, modeled after the French and Soviet systems, was established in 1928, just a year before the nationalist government was established in Nanjing under Chiang Kai-shek.

Twentieth-Century Influences on Science and Science Education in China

In observing the history of modern science and science education in China, I use five lenses to put science education, formal and informal, in perspective: the nationalistic, the political, the linguistic, the cultural, and the pedagogical.

First, the nationalistic lens informs us that modern science and science education as imported culture from the West have been welcomed and embraced by Chinese people. Essentially this is because it is believed science and science education will rejuvenate and strengthen a China that has lagged far behind the West, scientifically as well as economically and socially (Wang 2002). Recently, Xi Jinping, head of the Communist Party of China (CPC) and chairman of the People's Republic of China, has called for the "China Dream," which clearly resonates with the nationalistic notion of saving China through science and technology, a lasting dream of the Chinese people for more than a century. The revelation of the nationalistic lens for the understanding of current science education in mainland China is that receiving a science education is for Chinese students to help rejuvenate and strengthen China, a kind of collective conscientiousness that has motivated generations of Chinese teachers and students alike to pursue teaching and learning science (and technology).

Second, in line with the nationalistic lens, the political lens provides us with an understanding of science education in China that is, in a sense, characteristic of Chinese education in general, tracing back to the early twentieth century. The May Fourth Movement of 1919, a significant protest movement at this general time, started as a students' protest against Western and Japanese encroachment on Chinese sovereignty at the Versailles treaty negotiations. Leaders of this movement, including a few scientists, called for the introduction of "Mr. Democracy" and "Mr. Science" into China to reform its traditional pattern of culture and politics (Wang 2002). As two banners of the May Fourth Movement, many of the Chinese intellectuals adopted ideas of science (Mr. Science) and democracy

(Mr. Democracy) to inject into the minds of generations of Chinese teachers and students alike, a desire of modernizing China partly by teaching and learning science and technology.

In recent decades, such a political motivation among Chinese science educators and students has shown itself under the communist regime as well, in which "love of science," a slogan together with others, has been instilled into the minds of young children of many generations.

The third lens, the linguistic one, connects with science education through the revamping of the Chinese written language. One of the most influential philosophers, Hu Shi (1891–1962), first studied agriculture in Cornell University in 1910 and, having found his interest in philosophy a year later, transferred to Columbia University to study philosophy under John Dewey. While still there as a doctoral student, he initiated a movement for the vernacularization of the Chinese language as part of the New Culture Movement early in 1917 (Wang 2002). This has had tremendous influence on science education in China, as it has made it possible to translate Western scientific terms into the modern Chinese written language.

Writing about the influence of the New Culture Movement on physics education, for example, Jianjun Wang (1997), a Chinese American professor of science education now teaching at California State University, Bakersfield, comments that

> Had physics been explained in classical Chinese, students would have been burdened by the tedious language decoding requirement. In reality, classical Chinese was too outdated, and used only in written communications among a small group of Confucian intellectuals. The thorough reform of classical Chinese in the New Culture movement had made physics more accessible to the general public, and differentiated physicists from classic scholars in terms of the language style. (p. 335)

Taking as an example, the modern term for science is *kexue*, whereas before the 1910s "science" was translated into *gezhi*, a term borrowed from the ancient Chinese set phrase *gewu zhizhi*. As we use Chinese characters in written language rather than phonetic writing, learning and teaching science in Chinese language presents special difficulty for students and teachers alike. For instance, the concept of energy causes misunderstanding for Western students. However, similar misunderstandings happen with another concept "force" for Chinese students. The Chinese term "force" in daily life implies "energy" or "power" to some extent (Gao 1998).

The cultural lens, the fourth one, brings us to an insight into how science education in mainland China operates, within and outside schools. Although modern science seems to be perceived to be universal everywhere across the world, science education, both formal and informal, within China is taught and learned against the backdrop of Chinese culture in general, thus coloring the curriculum, pedagogy, and assessment of science education.

This is given great attention by Keith Levin (1987), a British comparative educationist, who, in studying science education after a study tour of China in 1984, alerts his readers of the need to "recognize the unique features of provision that make it unlike that in other countries. These include . . . the cultural traditions that shape pedagogy, the ideology of the state, and the rapidity with which changes have been taking place in the recent past" (pp. 420–421).

And finally, the fifth lens, the pedagogical one, which is interwoven with the cultural lens, enables us to see "special characteristics of Chinese science education" (Levin 1987, p. 440). As modern science came to China at the turn of the twentieth century, European pedagogy was introduced into China simultaneously to fit with the newly established teacher education system. At the very beginning of the twentieth century, the German educationist Herbart's pedagogy and especially Herbartianism were introduced and immediately became prevalent across China by way of translating Japanese pedagogical literature. This school of pedagogy was to set the tone for Chinese pedagogy and had huge impact on teaching, learning, curriculum, and assessment of almost all school subjects, including science.

However, the pedagogical lens is diverse and complex in the landscape of Chinese education in general and science education in particular.

After the May Fourth Movement which broke out as a national protest against Japanese aggression, China moved toward US educational sciences, especially following the academic tour of John Dewey in China from 1919 to 1921. For the next three decades until 1949 when the communists came to power in mainland China, it was the American educational sciences – including curriculum theory and the then newly emerging science education research – which came to dominate Chinese pedagogical discourses and exert considerable influence on educational practice.

In the middle of the twentieth century, there was a dramatic turnabout in the pedagogical discourses and theories as the CPC won victory against the nationalist government under Chiang Kai-shek. In the 1950s, the American educational sciences that had been pervasive in Chinese science education were critiqued and swept away as bourgeoisie. Instead, the Russian pedagogy was introduced into mainland China, which emphasized didactics and subject didactics. As a result, the Russian educationist I. A. Kairov (1893–1978) took place of John Dewey in communist China.

In the 1960s and 1970s, after the Sino-Soviet rift arose in 1960, the Russian influence was criticized too, and China began to explore its own way to establish a pedagogy based on Marxism and Maoism with Chinese characteristics. However, the decade-long Cultural Revolution (1966–1976), which caused a catastrophe for mainland China, rendered Chinese education into a wasteland. For example, the course content of physics, which has always been “king” among secondary science subjects in China, was reduced in most regions to only four components, the steam engine, the internal combustion engine, the electric motor, and the pump (Amidei 1980; cited in Wang 1997, p. 337).

The year 1978 saw the beginning of a new era for mainland China, initiated by the CPC’s new policy of reform and opening up to the world under the leadership of Deng Xiaoping (1904–1997). Russian theories of pedagogy were again introduced into mainland China, together with North American educational science and European pedagogies. For the past three decades or so, both the Anglo-American “educational science curriculum” paradigm and the Continental-European “pedagogy-didactics” paradigm have converged in mainland China. This has resulted in a mishmash of pedagogical or educational discourses, which show themselves in many textbooks, with titles such as *Curriculum and Didactics of Physics*, *Curriculum and Didactics of Chemistry*, and *Curriculum and Didactics of Biology*, in use for the preparation of science teachers, both preservice and in-service, in Chinese universities and colleges. Without question, these textbooks and others relevant to science education provide science teachers with the main professional knowledge base which, in turn, comes to influence science education practice in mainland China.

Recent Reforms in Science Education

With the historical background described above in mind, I focus in this section on recent reforms in science education in mainland China. Since 1978, when China emerged from the disastrous Cultural Revolution (1966–1976) and entered a new era heralding reform and opening up, Chinese science education has experienced two main stages of reforms. These reforms have gained their driving forces both from the dramatic social change and transformation within China over the last 35 years and from learning from other countries, especially the USA. The first stage of reforms lasted from 1978 to the end of the twentieth century, during which science education regained its status in the Chinese schooling system and then started to reform, while the second stage began around the turn of the new millennium and continues today. It features a more conscious combination of internationalization and localization of science education in mainland China.

The First Stage: Reinstating and Reforming School Science (1978–1999)

The first few years of the late 1970s and the early 1980s saw the reinstating and reestablishing of the schooling that had been destroyed at every level during the disastrous Cultural Revolution. From the mid-1980s to 1999, precollege science education was fine-tuned and consolidated with new syllabuses for primary science and biology, chemistry, and physics for junior high schools (grades 7–9) and senior high schools (grades 10–12).

In primary schooling, “nature” as primary science became part of the curriculum again. Although the course had a similar nomenclature as it did before, its structure, content, and pedagogy changed considerably as it borrowed directly from the reforms of primary science education in the USA. Beginning from 1977, Brenda Lansdown (1904–1990), a Harvard professor of science education specializing in primary science, came to China for academic visits many times, involving herself deeply in the reforms of Chinese primary science. One of her major works – *Teaching Elementary Science: Through Investigation and Colloquium* (Lansdown et al. 1971) – was translated in 1984 into Chinese and printed many times and has since become a primer for primary science teachers, both preservice and in-service.

In terms of discipline structure, “nature” as primary science emphasized conceptual understanding of science rather than presenting just factual knowledge about nature, as it had done before in China. The curriculum content covered in the course and in student textbooks was systematic, coherent, and balanced in terms of physical science, life science, and earth and space science, i.e., the modernizing of primary science was in line with the US elementary science at that time.

Based on the reform experiences of the 1980s, “nature” as primary science in the 1990s became more consolidated as the new syllabus of 1992 for “nature” appeared and new textbooks in line with the syllabus for pupils and teacher guides were available.

In secondary schooling, science education in mainland China was heavily influenced by the USA as well. In 1979, Paul DeHart Hurd (1905–2001), then emeritus professor of science education at Stanford University, headed a group of American science educators that visited China, the first such visit since 1949. In response, Ye Liqun (1921–2000), then the head of People’s Education Press, led a group of ten Chinese science educators to visit the USA at the invitation of the US Ministry of Education in 1982 (Ye 1982). Both these visits opened the horizons on the part of Chinese science educators and effected a change in policy of science education in mainland China.

Another influence of American science education on mainland China came from taking advantage of the USA and other then industrialized countries’ science curriculum projects and materials developed in the 1960s and 1970s to update and modernize the curriculum of science disciplines for mainland China. In developing science programs for physics, chemistry, and biology and textbooks of each discipline for students and teacher guides for science teachers, Chinese science curriculum developers (scientists, didacticians of science disciplines, and experienced science teachers) in 1977 examined and adopted much from other countries, such as Japan, Western Europe, and most commonly the USA. They paid particular attention to the US curricula such as PSSC, CHEM Study, CBA, BSCS, and ESCP and took ideas from them for use in the unified textbooks they compiled for physics, chemistry, biology, and geography, respectively. In general, it appears that “teachers found many topics to be too theoretical for the majority of students to comprehend at the grade level for which the texts were originally written” (Hurd 1985).

As in primary schools, science curricula in secondary schools were revised and fine-tuned beginning in 1988 and completing in 1992, when new versions of physics, chemistry, and biology were proposed and new editions of textbooks for these science subjects compiled accordingly. This new wave of reform in secondary science focused on the following changes:

The Change of Science Education Goals. Due to the promulgation of the 9-year compulsory schooling law in 1986 by the central government, science education in junior high schools began to change its goals from a somewhat elite education model to a mass education model, so students’ interest in physics, chemistry, and biology were more emphasized in the syllabuses of each science discipline (Wei 2008).

One Syllabus Versus Various Textbooks. Formerly Chinese science education had been characterized by only one syllabus for each science subject at the secondary level and only one kind of unified textbooks for each science subject according to this syllabus which was produced by the official publishing house – the People's Education Press. In 1988 the Ministry of Education followed a new policy of "one syllabus vs. various textbooks" so that different types of high schools could choose them according to their needs and levels. Characteristic of these new textbooks were more up-to-date and refined scientific knowledge, more attention to development of competences in students, more emphasis on what was termed "double basics" (basic knowledge and basic skills), and strengthening the linkage between science education and the social and personal life of students. For instance, the idea of STS was introduced to serve the purpose of connecting (scientific) theory with practice (i.e., social and personal life), and STS contents were added into these textbooks (Wei 2008). In spite of these endeavors, however, the dichotomy of education for quality (*suzhi jiaoyu*) as a new policy of the Ministry of Education and examination-oriented education (*yingshi jiaoyu*) as a reality of the status quo of Chinese education was becoming more and more serious.

Integrated Science Programs on an Experimental Basis. One of the significant breakthroughs in science education reforms during this period came from Shanghai and Zhejiang province. In 1988, the Ministry of Education allowed both to experiment with their own curriculum and textbook production. In science education, both Shanghai and Zhejiang province started an integrated science program for grades 7–9 students in junior high schools. Despite strong opposition from conservative forces when the new curriculum was implemented in the 1990s, the integrated science curriculum in Zhejiang province made progress and converged into the new wave of national science education reforms in the new millennium.

The Second Stage: Science Education Reform Featured with a Combination of Internationalization and Localization (2000–2013)

Around the turn of the new millennium, a new wave of reform in schooling in mainland China began with an outlook toward the twenty-first century. To a large extent, this wave of reform in school science was more consistent with the mainstream of international science education reforms than previous reforms had been, just as the Chinese economy began to be more integrated into the world economy.

The new millennium saw the promulgation of the Ministry of Education's guiding plan titled "Framework for Basic (i.e., primary and secondary) Education Curriculum Reform" in 2001. It also witnessed the shift back of educational discourses from didactics to curriculum studies, such as "curriculum standards," which had been prevalent in the nationalist era of the 1930s–1940s. This now took place of "syllabuses" which had been in use since the 1950s when mainland China learned from the Soviet Union in many respects, education included. For the first time in Chinese educational history, primary science was to become a national curriculum that would replace "nature" and involve every child in science learning from grades 3 to 6.

In accord with the "framework" mentioned above, curriculum standards for primary science (grades 3–6), for junior high school science (grades 7–9), and for junior high school physics, chemistry, and biology were produced by committees of curriculum standards writing teams consisting of science educators and experienced teachers and published by the Ministry of Education in 2002. For senior high schools (grades 10–12), curriculum standards for physics, chemistry, and biology, respectively, were published by the Ministry of Education in 2003. In these science curriculum documents, such discourses as "scientific literacy," "inquiry-based teaching and learning of science," and "nature of science" were officially adopted, as by then the American science education reform documents of "Project 2061" (AAAS 1989) and the National Science Education Standards (NRC 1995) had all been translated into Chinese and became the most important reference materials for drafting Chinese science curriculum standards. Thus there was further internationalizing of science education in mainland China.

In contrast with the former syllabus for separate science disciplines, the new science curriculum standards have embedded the following basic ideas: science for all, promoting the development of every student, embodying the nature of science, emphasizing scientific inquiry, and reflecting the developments of contemporary science. To a large extent, these standards have integrated the science disciplines, since the conception of scientific literacy encompasses the overall purpose of science education throughout the science curriculum from primary schools to senior high schools. “Science literacy” is defined as consisting of four dimensions: (1) scientific inquiry (processes, methods, and competencies); (2) scientific knowledge and skills; (3) scientific attitudes, emotions, and values; and (4) the relationship of science, technology, and society (STS). To implement these new science curriculum standards, new textbooks have been compiled for primary science, integrated science textbooks for junior high, and physics, chemistry, and biology textbooks for both junior and senior high schools. Junior high schools are expected to choose either the integrated science textbooks or separate science disciplines for their students.

In order to promote the science education reform, one of the most important measures taken by the Ministry of Education is to train science teachers. In many universities and colleges, newly established centers of the curriculum reform have been founded, and science educators there plus temporarily employed experienced science advisors and teachers have become trainers. They offer short-term courses (normally 3 or 4 weeks) consisting of lectures given by scientists, didacticians of science disciplines, and expert science teachers, observing excellent science lessons given by expert teachers, participating in discussion and interaction with peers, etc.

The experimental exception to the national primary science education program is the “Learning by Doing” project. Originally imported from the French “La main a la pate” program in 2001, the “Learning by Doing” project was initiated by the China Association for Science and Technology (CAST) and the Ministry of Education jointly under the leadership of Prof. Wei Yu. It focuses on children in kindergartens and elementary schools having exploration study through hands-on activities. At present, nearly 20 regions across the country are involved in this project.

Summary

Science education in mainland China has experienced a fluctuation full of ups and downs over the past century. Originally imported from the West, it is clear that science education has become institutionalized in the Chinese schooling system and has tried to permeate the Chinese culture. Over the past three decades, science education in mainland China has been more and more integrated into the mainstream of international science education reforms, yet at the same time it has retained the Chinese way and thus is different from that of other countries in many ways.

Cross-References

- ▶ Cultural Influences on Science Education
- ▶ Didaktik
- ▶ Science Teacher Education in Mainland China

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Science Education in the Non-West

► Japan, Science Education in

Science Exhibits

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Science exhibits are displays that explore scientific objects, knowledge, process, and debate in an approachable, understandable manner. They deliver multiple levels of information and accommodate different learning styles.

Great science exhibits excite the emotions and stimulate the intellect while driving home an interesting, inspiring message about an aspect of science. After all, science exhibits are part of the informal learning experience, where emotional response usually paves the way for learning and engagement.

Science exhibits assume an endless variety of forms and styles, from dinosaur skeletons to gesture-controlled computers to dioramas to historical artifacts to interactive mechanical devices. The diversity of science exhibits is a reflection of the wide variety of institutions that create and house them.

History

Museums, in their modern sense as public institutions focusing on collections, research, and education, have been with us for over 500 years. The earliest museums focused on art and religious artifacts, and it was not until the eighteenth century, well into the Age of Enlightenment, when science emerged as a topic worthy of consideration for a museum.

The first science exhibits were collections of specimens gathered by nobility or other men of independent means. Naturalists, explorers, and traders were moving about the world with greater mobility and were able to gather impressive collections of specimens – common, rare, or just strange, the always popular "curiosities."

One of the earliest public collections of specimens was put together in the late eighteenth century by Sir Ashton Lever, whose initial fascination with birds led to the creation of an impressive aviary. As his live birds inevitably passed on, many were stuffed and mounted, growing into a formidable collection. His holdings expanded as all manner of other specimens were brought to him. His collection outgrew his country home near Manchester, and he moved it to his London residence and, in a pioneering move, opened it as a museum for public visitation in 1774.

While Sir Ashton showed the way, the British Museum began to amass and display the world's largest collection of natural specimens, leading to the creation of the separate Natural History Museum in South Kensington in 1881, creating a public treasury of the wonders of the natural world. In the early museums, exhibits were seen as basic teaching tools, unabashedly didactic and key to illustrating our rapidly growing understanding of the planet. Scientists combed the world for unusual expressions of the natural world, and thousands upon thousands of plant, animal, and mineral specimens were carefully collected and put on display, both for the growth of the science and for the edification of the public.

While stuffed animals and mounted insects made for a natural attraction, it was perhaps not quite so obvious that the stuff of science – the tools, technology, and engineering – also deserved pride of exhibition and scholarship.

Industrial society, in the form of tools, technology, and engineering, first appeared in museum exhibits in the Musée National des Techniques in Paris. A decree from the post-Revolutionary government in 1794 mandated the creation of a public depository for the rapidly expanding inventory of tools and inventions, plus the documentation that led to their creation. The physical facility opened in 1799.

At the dawn of the twentieth century, the newly founded Deutsches Museum in Munich took its exhibits in a different direction. Still didactic, still intent on teaching, it not only cataloged the past, it celebrated the contemporary. The Deutsches Museum was arguably the first institution to systematically collect and display the tools, instruments, and inventions of science and then add a layer of engagement through working models along with illustrations and diagrams explaining how things worked. It examined how technology affected the everyday life of Germans. The exhibits were more than a catalog of relics.

The idea of what a science exhibit could be evolved further in the 1930s with the opening of the Museum of Science and Industry in Chicago (1933) and the Palais de la Découverte (1937) in Paris. Both institutions developed exhibits that encouraged visitor involvement, whether it be walking through an enormous model of the human heart or actually conducting a simple experiment in a museum laboratory. These exhibits explored concepts like electricity and ecology and expressed science as a process, as opposed to just collections.

These important first steps were more fully realized in the 1960s and 1970s when exhibit designers began wholeheartedly to tackle the process of scientific investigation. In 1969, the Exploratorium in San Francisco and the Ontario Science Centre in Toronto opened their doors. The interactive science exhibit defined the entire personality of these institutions and captured the public imagination. The museum experience had been transformed from artifacts and specimens to the act of discovery itself. In these bold new institutions, the visitor became central to the act of learning. Artifacts and specimens were still present, but the most profound and popular exhibits were the ones in which the visitor took some control of the outcome and thus, in the well-designed examples, had a chance to behave and learn like a scientist.

There were levers to push, ropes to pull, balls to drop, and pendulums to swing. The choreography of action was intended to illustrate the laws and patterns in the world around us. After all, science simply states that the universe behaves according to a certain set of rules, and through experimentation and observation, we can figure out those rules. At the Ontario Science Centre and the Exploratorium, visitors were encouraged to test the rules for themselves. This gave rise to many famous and widely emulated exhibits – the Bernoulli Blower, the Van de Graaff generator, colored shadows, construction of catenary arches, and dozens of others.

Another great step forward in science exhibit content that gained momentum in the 1980s was the exploration of the social and cultural context of science, from AIDS to climate change to genetic modification to cultural bias in science. As science progresses, it not only increases our understanding and capabilities, it also often challenges our moral compass, and this is now a central part of the exhibit experience at many science museums around the world.

With the advent of ubiquitous digital connectivity, many exhibits are now being designed with internet elements as a core component. Prior to the 1990s, science centers and museums often featured exhibits that explained technology – the wonders of the computer and binary language and transistors. Those exhibits have largely disappeared, due in no small part to the rapid pace of technological change. Exhibits about technology show their age in short order.

As technology progresses, exhibits now feature technology as a central part of the experience. Multiuser touch screens, social media, mobile apps, and group interaction through smartphones are now a normal part of the exhibit landscape, but these advances will again soon seem quaint as new technology emerges and becomes even more an ordinary part of our everyday lives.

Signature Science Exhibits

Museums and science centers often have exhibits that are a core part of their personality and history. They develop and nurture these iconic exhibits to be part of their personality, part of their brand.

One of the best examples is the coal mine tour at the Museum of Science and Industry in Chicago. This exhibit is better referred to as an "experience," as it involves a descent into and tour through a simulated coal mine under the museum. The coal mine opened in 1933 and MSI calls it its first "interactive experience." It is a much-beloved part of the MSI experience. After 80 years in operation, and much retooling and upgrading, it remains a destination within the facility where parents who visited as children bring their children, passing on a sentimental connection to the museum from generation to generation. Similar sentiments surround the coal mine experience at the Deutsches Museum in Munich.

The Theater of Electricity at the Museum of Science in Boston is a core part of that museum's experience. It features massive electrostatic generators that were part of Robert Van de Graaff's teaching laboratory at the Massachusetts Institute of Technology (MIT). The artifacts are impressive in their own right, both technically and historically, but they are still operational and the museum uses them every day in a spectacular show on static electricity.

For decades, a Van de Graaff generator with a young girl's long hair billowing out above her head was the de facto brand image for the Ontario Science Centre in Toronto. The image wonderfully captured the essence of the interactive science center experience – exhibits that encouraged audience participation and which revealed spectacular and unusual results.

It is no accident that some of the largest museums in the world place dinosaur skeletons in positions of prominence. Since 1905, a massive diplodocus skeleton has dominated the Central Hall at the Natural History Museum in London. Iguanodon skeletons from a famous Belgian fossil pit have been the headline exhibit since 1882 at the Royal Belgian Institute of Natural Sciences in Brussels.

The Carnegie Science Center in Pittsburgh is home to a massive, highly detailed, and very much-treasured model railroad set in the hilly terrain of western Pennsylvania. It has been a work in progress at the museum since 1954. For 30 years, a live porcupine and beaver (actually, a succession of porcupines and beavers) have been unofficial mascots of Science North in Sudbury, Canada. The walk-through heart at the Franklin Institute in Philadelphia; the Paper Machine at Teknikens Hus in Luleå, Sweden; and the Gravitram at Questacon in Canberra (and other museums) are wonderful examples of exhibits that generations grew up with and that provide a "familiar face" for returning visitors.

Types of Exhibits

It is difficult to reduce the countless thousands of science exhibits to just a few categories, but there are some general broad groupings that help understand the character of an exhibit.

In reality, many exhibits will display elements of different categories, since there are no overarching rules for creating every exhibit. Each exhibit is an individual creation, and its success depends on how well its design deals with the intended message, visitor expectation, visitor behavior, and context.

Teaching Versus Learning

Didactic exhibits emphasize information and instruction. At its most basic level, a specimen, artifact, or phenomenon is presented with some combination of text, graphics, and audio to explain what visitors are viewing. This is very much a one-way teaching conversation from exhibit to visitor. It is perfectly appropriate for many exhibits, particularly when the item on exhibition has some profound historical or technical significance.

At the other end of a very broad continuum are the interactive exhibits that can be loosely categorized as "constructivist." Constructivism posits that learning comes from meanings created, or "constructed," by individuals building upon what they already know. In constructivism, learning is an active, social process. It may or may not come with instructions. It allows that learning takes time and that we build new knowledge through playing, testing, pondering, and thinking. Good interactive exhibits encourage this process by providing tools and context and put the acquisition of new knowledge, the learning, in the hands of the visitor.

Whether one is better than the other depends entirely upon the needs of the exhibit. In the end, the success of either approach, or anything in between, is only as good as its design and implementation.

During a visit to a science museum or science center anywhere around the world, a visitor can expect to encounter these types of exhibits:

Specimens

Specimens are the stock-in-trade of natural history museums – the bones, fossils, mounted animals, minerals, and other things collected from the natural world. They were also the very first science exhibits.

The earliest specimen-based science exhibits were heavily didactic, with an emphasis on teaching a specific piece of content, but usually with a sense of the dramatic. One of the earliest major science exhibitions was the Crystal Palace Dinosaurs, opened in 1854, a collection of life-sized dinosaur and mammal sculptures. It was a radical display in the mid-nineteenth century but then, as now, dinosaurs proved to be hugely popular with the public.

Some of the best-known and most popular exhibits around the world are based on outstanding collections of specimens. Museums off the beaten track, like the Royal Tyrrell Museum of Palaeontology in Drumheller, Alberta, or the Museum of the Rockies in Bozeman, Montana, attract huge audiences to see their magnificent displays of dinosaurs and other fossils.

Whether its fossils, minerals, gems, preserved animals and insects, bones, plants, or others, museums around the world give us a view into the wonder of the natural world through displays of their exhaustive collections.

But not all specimens are inanimate. At the Insectarium in Montreal, over 150,000 insects and arachnids are on display or in the collection. Live ants and bees are also on show in "vivariums."

Artifacts

Since the opening of the Musée National des Techniques in Paris at the very end of the eighteenth century, museums have been collecting and exhibiting the tools and technology that are the legacy of science.

One of the busiest museums in the world deals predominantly in artifacts of science and engineering – the Smithsonian National Air and Space Museum in Washington, D.C., where millions visit each year to see iconic airplanes and spacecraft, the real stuff of our technological history.

The Science Museum in London displays artifacts with profound historical significance, from the earliest surviving steam locomotive to a WWII Spitfire to early medical instruments.

Any museum is much more than just its artifacts, but through these collections of significant objects, we preserve, illuminate, and teach the history of science. And as an exhibit, the real artifact will always have much greater emotional impact on audiences than a replica.

Dioramas

Dioramas are the detailed recreation of a scene that incorporates three-dimensional objects surrounded by a carefully rendered background to provide context, perspective, and a sense of distance.

While dioramas are used in museums of all types, they are particularly associated with natural history museums as a technique for displaying posed animal specimens in portrayals of their natural environment. These displays can provide precise illustrations of animal behavior and habitat.

The earliest ecological dioramas are credited to Carl Akeley who created dioramas at several American museums. His exceptional craftsmanship is still on view at the American Museum of Natural History where the Akeley Hall contains what many consider to be the best dioramas ever created. His Mountain Gorilla diorama is perhaps the most famous.

Hands-On

The terms "hands-on" and "interactive" are often used interchangeably, but there are distinctions. Unfortunately, both terms suffer from vague, imprecise definitions and from overuse. They suggest an intent without providing any particular prescription for how to accomplish it.

Designers have tried to expand upon the term by coining variants like "hands-in" on "minds-on," encouraging greater consideration for how visitors manipulate and think about the challenges put before them.

One of the most ubiquitous interactive science exhibits, found in dozens of science centers around the world, is the Bernoulli Blower, first made popular at the Exploratorium in San Francisco. Frank Oppenheimer, the Exploratorium's founding director, used this exhibit as an example of how a well-designed interactive exhibit provided many different ways to interact. In this exhibit, a light beach ball or volleyball sits atop a stream of air directed upward through a nozzle. Visitors can tap on the ball and experiment with its movement in the stream of air. They may toss other objects into the stream or let their hair fly over their heads, or groups may toss the ball back and forth through the stream. Or some people direct the air up their shirts for the pleasant cooling sensation.

In this exhibit, there is no particular right or wrong. There are scientific principles that are illuminated and can be explored and toyed with, but at its core, the exhibit encourages experimentation and allows the visitor to take considerable control of the outcome. The exhibit is much less concerned with teaching a specific point than it is with encouraging visitors to observe and explore certain types of cause and effect.

Oppenheimer also felt that this may not be enough. With a little more thought and design, he figured this interactive exhibit could do an even better job of encouraging meaningful experimentation, and to that end, there are many variants of this exhibit in science centers around the world.

Science centers have been building "hands-on, interactive" exhibits since the late 1960s, and each one is still created from scratch, owing more to art than science, as each new exhibit sets its own rules for visitor involvement. As a result, in a visit to almost any science center, we see interactive exhibits that truly dazzle and others that fail to accomplish much at all.

Computer Based

Technology is allowing new techniques for engaging visitors in content. In the 1970s, 1980s, and 1990s, many science museums and centers developed exhibits about technology, introducing visitors to microprocessors and state-of-the-art tech innovation. Now that computer technology is so thoroughly embedded in our lives and advancing so rapidly, the focus has rightly changed to using technology to enhance exhibits and the visitor experience.

The museum world is embracing virtual exhibits – online catalogs, virtual reality, simulations, quizzes, multi-touch screens, smartphone apps, and countless others – and they are now an accepted, even expected, part of the museum landscape. Computers offer opportunities to simulate reality or construct scenarios that would not be possible in the real world. RFID chips allow visitors to track their progress through a museum. The Tech Museum of Innovation has built galleries of virtual exhibits in Second Life, doing things in the virtual world that are not possible in our physical space, extending the exhibit experience beyond the walls of the museum itself.

With the advent of more powerful processors, we are now seeing the first generation of "augmented reality" exhibits in which technology monitors physical interaction and provides real-time information or feedback. In an augmented reality exhibit, a museum visitor may manipulate an interactive exhibit, while a screen provides an animation that illustrates some element of how the physical interaction is controlling the environment. A smartphone or tablet pointed at an exhibit can produce a 3D avatar "host" who provides background information about the exhibit.

Outdoor Science Parks

Indoor environments come with restrictions. There is no wind and little or no natural light, and space is usually at a premium. Outdoor spaces provide the opportunity to create exhibits that involve the sun, wind, rain, and snow of the natural world.

They can involve water and sand and other materials that need to be tightly controlled indoors. And very often, the outdoors allows for very large exhibits that are impractical indoors, from large artifacts like airplanes to oversized levers that lift heavy objects to parabolic dishes that transmit whispered conversations across significant distances.

Unusual Media

There is no limit to the imagination found within science exhibits. The intersection of science, art, and other disciplines provides some of the most compelling artifacts of science.

A striking example is the Glass Flower gallery at the Harvard Museum of Natural History. It is a collection of about 850 plant and flower models, meticulously crafted from glass over five decades by a father-and-son team. The flowers were commissioned by a Harvard botanist who wanted high-quality models for instruction in botany. Exhibits like the glass flowers combine consummate artistic skill with scientific integrity.

Exhibitions of photography based on scientific images have become more common as imaging techniques have become more sophisticated. Images gleaned at the nanoscale or the cosmic scale come laden with scientific content and a profound aesthetic appeal.

Evaluation and Success in Exhibits

One of the most compelling questions about science exhibits is their effectiveness. Does an individual exhibit convey a meaningful message? Do exhibits increase an individual's understanding of science, and if so, how?

This is a difficult question to answer since museums and science centers are designed as places where individuals construct their own experience, choosing what to see, what to read, what to do, and how to explore the museum and its contents.

Researchers have tried to measure cognitive changes produced by exhibits and in a similar fashion to how we measure learning in schools. This has been problematic, since exhibits and the learning objectives for exhibits are different than those in the formal learning system. At school, specific content is taught and then retention and understanding by the student is measured, usually through exams. Exhibits don't work that way.

John Falk and Lynn Dierking have extensively studied how museum visitors interact with and learn from exhibits. Through their research, they have developed the "contextual model of learning" which proposes that how and what visitors learn in museums depend on their personal backgrounds, social interactions, and the physical environment. Decades after a visit, visitors often remember the physical environment in a museum more than individual exhibits. Understanding visitors' expectations and building appropriate physical contexts for exhibits are key to creating a powerful experience.

Research into how people learn gives strong clues about what sort of behaviors are indicative of learning. At Science North in Sudbury, Canada, Chantal Barriault identified a suite of behaviors that indicate different levels of cognitive engagement with exhibits. Evaluators observe visitors interacting with specific exhibits and track different types of behavior. Actions like acknowledging relevance and seeking or sharing additional information are strong indicators that learning is taking place, although the specific learning is often highly individualized for each visitor.

A related line of investigation has been intensively pursued at the Exploratorium in San Francisco. Their researchers measure exhibit effectiveness by assessing the quality of visitor interaction with the exhibit and the clarity of message the exhibit is conveying. They coined the term "Active Prolonged Engagement," or APE, to capture the key elements of a quality visitor experience with an exhibit. Visitors need to be *active*, doing things, in control of the outcome. Their exhibit experience should be *prolonged*, spending time with the exhibit to experiment and test. And they should be *engaged* and be stimulated intellectually and emotionally.

A framework like this provides an expansive, yet measurable, definition of what an exhibit should be. It provides a basis for carefully assessing an exhibit's effectiveness and is particularly useful for helping exhibit design team make an initial prototype better.

One of the biggest paradoxes in interactive exhibits is that it is possible that the activity, or the manipulation by visitors, can actually reinforce faulty impressions about how the world works. This is perhaps one of the biggest shortcomings of interactive science exhibit design, and it reinforces the need to prototype and evaluate exhibits, particularly interactive ones.

Creating Exhibits

The process of exhibit development varies widely between institutions and between projects, but there is a general road map that guides the process. Some museums have internal scientific and design teams to lead this process, but many rely on outside companies with specialized exhibit design, prototyping, and fabrication experience.

Museums and science centers usually create galleries or zones of themed exhibits. Exhibits supporting a similar theme are typically grouped together. This makes life simpler for the visitor, since they need cues as to how to behave (are these exhibits hands-on or not?) and what the overarching scientific and educational messages may be.

The first step is a conceptual plan that answers some key questions: Who is the audience? What are the educational/cultural/scientific messages? What will visitors do when they visit the exhibit? The conceptual plan lays the groundwork so that more detailed design has guidelines for development.

From the initial conceptual plan, ideas are refined to a schematic stage that describes what visitors will do with a specific exhibit, as well as the general dimensions and basic construction design.

Design development, up to and including final design, takes the exhibit to the level of detail necessary for fabrication. This is a challenging and complex process that requires creative, insightful solutions that are usually different for every individual exhibit.

During the schematic and design phases, prototypes are often constructed to try to answer very specific design challenges, especially for interactive exhibits. Prototypes provide important proof-of-concept feedback. They help designers understand how different materials work and how visitors will interpret instructions. It is unreasonable to expect that the first design of an interactive exhibit will work exactly the way it is expected to. Testing with prototypes, refinement of design, and listening to the exhibit users are all critical parts of creating good interactive exhibits.

In the 1990s, another important design element was introduced, that of "universal" or "accessible" design. This thoughtful approach to exhibit design provides equal access and enjoyment for everyone in the intended audience whether they are walking, wheeling, young, old, or physically disabled. Good universal design makes a better exhibit experience for everyone.

After the final design stage, specialized fabricators create detailed fabrication drawings and instructions so that they can build and install the exhibit according to the design team's vision.

Further evaluation of the installed exhibit helps an institution to refine and improve it so that visitors engage, explore, and learn.

Cross-References

▶ Interactive exhibits
▶ Museums
▶ Visitor Studies

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Science Fairs

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Science fairs are events at which students display and discuss investigations they have conducted in areas of science, mathematics, engineering, computer science, and other areas (for instance, in some jurisdictions, psychology-oriented projects are included). Most often, science fairs are competitive events where projects are ranked and prize winners are chosen, although in some jurisdictions (such as the CREST (CREativity in Science and Technology) event in Australia), there are noncompetitive events. Science fairs have a long tradition in many jurisdictions around the world; at a recent international competition event (the Intel International Science and Engineering Fair), there were projects from 70 countries. In the United States, the genesis of science fairs was a science club movement that began in the 1920s, building to 600,000 participants within 20 years. These led to the first National Science Fair in 1950, and over the following decade science fairs gained considerable prominence as science itself gained a higher cultural value (related to technology such as atomic bombs ending WWII, the development of television and higher public awareness of science accomplishments). Currently, a country such as Canada, in which a national science fair started in 1962, has half a million students conducting science fair projects each year. Other large-scale competitions, such as the European Union Contest for Young Scientists, had an even later beginning (the progenitor of the EUCYS competition started in 1968).

Science fairs can be considered part of developing students' science literacy skills. Although subject to debate, the idea of science literacy can be broken into three essential parts: (i) science "facts," (ii) science investigation practices (skills related to investigating and creating "facts"), and (iii) science social practices (how facts come to be developed and accepted within the community of scientists, and outside influences on them such as the public and corporations). School science is often critiqued for developing understandings of "facts" but not the other two domains of science literacy. In fact, some argue that the directed ways in which school inquiry tasks are engaged are antithetical to the nature of authentic science. Science fairs may address this by helping students develop their understanding of the other two domains of science literacy through encouraging students to develop open-ended investigations within which they present and defend their work to others (judges, as well as other science fair participants and even the general public).

Much like formal science conferences, science fair projects are usually poster based with some artifacts present from the investigation, often including a detailed log and report book. The projects are set up for public viewing and each student has to give a short verbal presentation of their work (now sometimes supplemented by computer slideshow tools or video). Criteria for the formal judging are often available to the participants, although judges ask their own questions during and after the presentation by the presenter. Because of these poster and verbal presentations, science fair projects develop students' skills over and beyond those of just "science" but also in areas of critical thinking, problem solving, presentation skills, writing skills, argumentation skills, and others that are present in curricular documents for topics other than science.

Despite the positives that science fairs may offer, there have been many criticisms offered over the past decades. The judging process can be problematic since, in many circumstances, projects are judged by persons with an inadequate background for effectively evaluating the particular projects (this happens at all levels of science fairs). A high degree of corporate sponsorship, to the point that the commercial sponsors' name is in the name of the science fair itself, is considered by some to be problematic because of influences it has on attitudes about science-in-the-corporate interest. There is some suggestion that a bias in judging toward commercially viable science projects has led to students focusing on projects that are instrumentalist in purpose, designed to address specific problems that have commercial implications, rather than conducting science projects that are more in the realm of "pure science." The competition itself can lead to students feeling discouraged when their projects are not advanced and do not win mention or awards, and, consequently, they can develop negative attitudes about science. There have been calls for an alternative to the ranking/ribboning/prize-giving in science fairs for over 40 years. Discussions of science fairs in the media often focus on projects which are commercially oriented and, also, have a strong focus on the size of the prizes available (a recent junior high project in the United States won over $110,000 worth of prizes) and arguably help perpetuate traditional stereotypes about the practice of science. Often, students with greater access to resources (mentors, financial resources, etc.) are doing well in science fairs because they have a broader network of support than is available to most students, and thus science fairs are reinforcing and replicating socioeconomic status through these high prizes. Anecdotal evidence suggests that in many circumstances, parents have perhaps too active a role in the conduct of science fair projects, particularly in younger grades. The role of "science communities" also is considerably underdeveloped in science fairs, with projects often being conducted by solo participants with little interaction with peers over the student's engagement in carrying out the project, although, often in senior projects, there is participation with (quite senior) mentors. A final criticism about science fairs is that they often seem to strongly reinforce students using "the scientific method" (which has been roundly discredited as representing the actual practice of science in both the sociology and history of science literature) and, thus, may be misleading students about authentic practices of science.

More recently, online "virtual" science fair competitions have begun to have some prominence. The first were held in the late 1990s but these were mostly small scale. In 2011, the Google Science Fair began and, in its initial offering, there were 7,500 projects submitted to it – which were subsequently winnowed down to 60 semi-finalists, from which three finalists (from each of three age categories) and a grand prize winner were determined.

Cross-References

▶ Inquiry, Learning through
▶ Scientific Literacy

Science Festivals

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"Science festivals" comprise a large, growing, and diverse community of science communication events. In recent years, the number of events has increased dramatically, and science festivals can be found almost all over the world, from San Diego to Novosibirsk, from Mauritius to Iceland, and from China to Brazil.

Basically, the term "science festival" covers a public event where science is presented to the public. Initially the "festival" part referred to the similarity with arts, film, or music festivals but with science as the main content. Consequently, many festivals were organized as projects or even as public or private companies with multiple stakeholders. Others were smaller, organized by universities, research organizations, or nonprofit organizations.

A study carried out in 2008–2009 (Bultitude et al. 2011) points to the growing popularity of science events. Festivals have been particularly common in Europe, but new events are introduced all over the world, not least in the United States.

Edinburgh in Scotland staged the first annual International Science Festival in 1989, to be followed by several others in Europe during the 1990s. In 2001, the European Science Events Association, Eusea (originally known as EUSCEA), was founded. Now, 10 years later, the association has approximately 100 institutional members in 36 countries.

During the almost 25 years that have passed since the first international science festivals, the profiles, purpose, and philosophy of the events have evolved, and today's festivals display a broad range of activities, places, and formats. From the start, "raising public awareness of science and technology" often was the most important reason to organize an event. In 2012, "public engagement" and "public participation" have become equally, if not more, significant profiles of an increasing number of festivals and events.

Science education and science festivals, representing formal and informal learning, seem to form a reciprocally beneficial relationship. Many science festivals have a specific program targeted directly at schools, thus becoming a valuable additional activity to everyday work in school and to national curricula (Lerch 2005).

The face-to-face meeting between scientists and the public is a signature characteristic of science festivals. Another is the festivals' way of organizing events at "unusual places," where science not normally is discussed. Shopping malls, railway stations, and other public places create a neutral place and an environment that allows interaction between scientists and members of the public on equal terms.

The value of the direct meeting has been recognized also by science museums and science centers. To an increasing degree, exhibitions in these places are complemented by activities such as lectures, experiments, and science cafés. Such activities may well fall under the umbrella of "science festivals"; indeed, several members of the European Science Events Association are science museums and science centers.

The opportunity for the public to interact directly with scientists seems to be appreciated, by both parties. In recent years, science festivals and science centers have also used their goodwill and actual arenas for policy-based activities, such as citizen conferences, student parliaments, and citizen exhibitions. The position of a center or a festival as a neutral platform with a broad range of stakeholders is advantageous, although the mandate from policy makers is essential for the engagement of the participating members of the public (ZIRN and W-i-D 2011).

From a research point of view, science festivals are still to be investigated in more detail. Evaluations are carried out to some extent but with different methods and in different languages, and the results are not always publicly available (Bultitude et al. 2011). The number of published articles is low, but presentations at conferences such as Ecsite (the European network for science museums and science centers), PCST (Public Communication of Science and Technology), and AAAS (American Association for the Advancement of Science) regarding festivals and festival activities seem to become more frequent. The body of work being built up is beginning to provide a compelling case for the value of science festivals.

Cross-References

- ▶ Café Scientifique
- ▶ Museums
- ▶ Public Communication of Science and Technology
- ▶ Public Engagement in Science
- ▶ Science Circus
- ▶ Science Museum Outreach

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Science Fiction

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Keywords

Movies; Novels; Radio; Science in fiction; Science-themed fiction; Television; Theater

Introduction

Some entertainment media products, such as movies and television dramas, are created specifically to educate people about science. Many more are created primarily to entertain but nonetheless contain scientific information, scientist characters, or representations of other aspects of science. This science-themed fiction – including animated sitcoms, novels, radio serials, plays, comics, narrative-based computer games, and more – has the potential to teach people something about science. That potential may apply during leisure time when people consume the fiction purely for entertainment, in the classroom when a fiction text is incorporated into the curriculum, and in informal learning environments such as science shows or community theater when fictional elements are used to market the event or to engage audiences.

Often the first thing people think of when discussing fiction and science is the futuristic and fantastical genre of "science fiction," hence the title of this entry. But other genres of fiction – historical, romance, comedy, soap opera, satire, thriller, and the rest – are just as relevant (indeed, often more relevant) when they involve science-themed ideas, settings, plots, and characters. The term "science-themed fiction" is therefore a better way of capturing this range of possibilities.

Professionals concerned about the public image of science, including science teachers, have traditionally been wary of associating themselves with the science in fiction for several reasons. The scientific information in fiction is often incorrect, making science's defenders worry that it corrodes the public's scientific literacy. Scientists are often depicted in stereotypical ways in fiction (as nerds, as mad or evil, as middle-aged white men in lab coats, and so forth), which is frustrating for people trying to break down stereotypes if they feel fictional scientists are undermining their efforts. In addition, the dramatic or comedic or romantic or speculative elements of fiction can be seen as superfluous to learning and therefore as a distraction from the serious business of science.

This wariness has abated in recent years with science teachers and science communicators increasingly interested in using fiction to engage students' interest. Creative teaching methods and better understandings of the way people process fiction have demonstrated its potential utility for science education.

The two most pertinent questions about fiction for science educators are:

- Do people learn science from the fiction they watch or read for entertainment?
- If a fiction text contains incorrect scientific information, how can it be used effectively to teach science?

Learning Science from Entertainment Fiction

There is evidence that people sometimes learn scientific information from the fiction they consume for leisure. Most of the evidence comes from research into science-themed television programs, particularly medical dramas and soap operas containing health information, so this discussion will focus on that.

It is important to qualify what is meant by "learn scientific information." The evidence we do have suggests that television audiences do not passively and uncritically absorb the science content presented onscreen. Rather, people are generally aware of television's production contexts and conscious that dramas and comedies are created to entertain not primarily to educate. Viewers therefore make considered judgments about what information to believe or disregard, what to find out more about, and which programs to trust.

Some television dramas have successfully communicated important health information, educating viewers or prompting them to seek further information about the topic by raising their awareness of it. In some cases, this has changed viewers' attitudes or behaviors, primarily when dramas have addressed personally relevant and taboo health topics such as HIV/AIDS, sexual health, and family planning. Salience is a key factor in learning, and learning science from fiction is a relatively short-term phenomenon unless the information is reinforced at the time through other fiction texts or sources such as newspapers, websites, and school lessons. Fiction is also most effective for health education when backed up by corresponding changes in society at large: for example, a program promoting condom use has little material impact if audience members cannot easily obtain condoms.

Television drama succeeds in teaching people health information for a number of reasons. Its spoken-word format reaches people who are illiterate or lack confidence in reading. The private location of television viewing enables health messages to be regularly delivered directly into people's homes. The entertainment focus of television drama is its greatest strength. The emotional problems and everyday ethical dilemmas characters deal with are a major draw card for audiences, so packaging health information into such situations and dilemmas, particularly if dramatic consequences ensue, can teach audience members about health. Information presented through highly emotional scenarios tends to make the information more memorable. Drama's nondidactic quality also appeals to audiences: they value the freedom to choose how to respond to any information presented, including the freedom to ignore it and just enjoy the show. Conversely, television audience members are frequently suspicious of documentaries because they feel documentary makers try to manipulate their beliefs by presenting their programs as "captured truth," when in fact they are constructed entities like other television products.

Television drama is particularly successful at science education if viewers feel that its characters, settings, and stories reflect their social reality and if the scientific information presented is relevant to their lives and community. Locally produced programs that are created and set in the countries or communities where viewers live are more likely to resonate with viewers. In some countries and communities, other fiction media such as community theater or radio drama can work equally well or better than television drama, if they are an accepted mode of entertainment for their audiences.

More research on this topic is needed, examining fiction media and genres beyond television drama and science disciplines beyond health. Greater methodological rigor is required too, to avoid limitations that render a study's conclusions questionable. For example, several researchers have used statistical correlations between people's understanding of a scientific topic and their television viewing habits to conclude that television fiction teaches people science (including incorrect or marginal science), but did not establish that television fiction was actually the source of the scientific information.

Teaching Classroom Science Using Fiction

Using science-themed fiction to teach science in schools has become increasingly popular in the twenty-first century. Up until the 2000s, there was little published work on this topic, only a small number of journal papers and books, including the landmark *Fantastic Voyages* (Dubeck et al. 1994), which detailed many ways teachers could use movies to teach science. In the early 2000s, more educators began publishing their ideas for using fiction to teach science, in books, academic journals, and websites (see, e.g., Cavanaugh and Cavanaugh 2004; Raham 2004). The published literature now includes effective ideas and even entire curricula for teaching physics, biology, chemistry, health sciences and medicine, earth sciences, psychology, engineering, environmental sciences, forensic science, and mathematics. Some of these have been used effectively to recruit nonscience students to science classes. While there is minimal quantitative evidence of their pedagogical value, what has been reported has been positive in terms of student numbers, student attitudes, and improved marks. Popular fiction themes have also been used as marketing tools to draw visitors to informal learning facilities such as science centers, often in record numbers, and with anecdotal evidence that visitors then visit other exhibits, their interest in science successfully piqued.

Most educators using fiction to teach science turn the weakness of incorrect fictional science into a strength, by prompting students to identify the factual errors in a movie clip (or a short television program, excerpt from a novel, etc.). When teachers present movies and other fiction texts in classes without prompting students to critique the factual errors, students tend to learn the incorrect science as if it were correct, so teachers are advised to be vigilant. Asking students to explain why the science presented is incorrect engages their critical thinking capacities, requiring them to apply their knowledge. More advanced classes can strive for higher-order learning outcomes. For example, students can consider (and calculate) what conditions in the story would need to change for the science presented to be correct. Some teachers use this approach to integrate multiple topics from the science curriculum, requiring students to employ different kinds of calculations or different areas of knowledge when critiquing a fictional scientific phenomenon.

Science fiction movies are most frequently cited as the type of fiction used this way. They have a unique capacity to visualize outlandish concepts such as global disasters, genetic engineering and cloning, space travel, artificial intelligence, and nanotechnology, enabling teachers to draw attention to the limits of real-life scientific knowledge by way of comparison. However, other kinds of fiction can be used to equally good effect. Appropriate fiction texts for this purpose usually have three things in common: (1) a demonstration of an incorrect (sometimes correct) scientific concept, (2) entertainment value to engage students' interest, and (3) stated parameters within which to explore the scientific concept. The first is an obvious necessity for teaching, and the second makes fiction fun to use rather than an additional burden on students, who may already be struggling with the scientific subject matter. "Stated parameters" here mean the set of conditions in which the scientific phenomenon is demonstrated in the fiction text, such as the size of a fictional hurricane, the speed of a spacecraft, or the source of genetic material for a cloning experiment. The parameters give students a starting point from which to calculate or evaluate the plausibility of the fictional scenario, much as worked examples in textbooks do.

Fiction has also been used to teach more socially oriented elements of science, such as the ethics of controversial science and technology or role-modeling good scientist behavior. Since ethics and other science, technology and society (STS) topics necessitate student engagement with human contexts – including understanding the feelings, values, cultural influences, power dynamics, political views, economic needs, and more that arise when people collide with science and technology – the ideal pedagogical tool will have those elements of human context as its core material. Science-themed fiction is one of the few resources available to teachers that situates science within a human context in this way. Its similarity to real life grants students some plausible stated parameters to work with (in this case human parameters), but its distance from real life enables classroom debates to maintain a hypothetical status unobstructed by the contingencies of real-world case studies.

An innovative approach to using fiction in the science classroom, which deserves further development, is to ask students to write a story about a scientist (Reis and Galvão 2007). Through this task, teachers can explore students' preconceptions about what science is, who scientists are, what scientific work is like, and where science sits within students' lives or the world as they see it. In line with work on redressing scientific misconceptions, this is a fruitful method of bringing to the fore ideas students have that they may not be fully conscious of thinking. The stories may then provide a focal point for discussion and for educating students about what science is really like.

Cross-References

- ▶ Alternative Conceptions/Frameworks/Misconceptions
- ▶ Broadcast Media
- ▶ Health Education and Science Education
- ▶ Imagination and Learning Science
- ▶ Learning Science in Informal Contexts
- ▶ Public Engagement in Science
- ▶ Science and Society in Teacher Education
- ▶ Science Theater/Drama

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Science for All

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"Science for All" is an aspirational phrase that has repeatedly embodied the hope that all members of society, and in the particular case of education, all students, will be able to share in some way in the richness of discovery, explanation, invention, and application that characterizes science as a great human endeavor. Probably first use of the phrase was as the title of a lecture in 1847 by James Wilkinson, a surgeon, in London. In his strong plea for sharing the benefits of science with society at large, he identified several points of hindrance that have been, and are still, evident in the many attempts that have followed to implement this aspiration through the education system.

One point was that the end for which scientific knowledge was sought and recorded by the learned and the end for which it is required by the multitude are not the same, but different. Others were that many scientists consider scientific knowledge as intellectual property to be transmitted unimpaired from generation to generation rather than rewriting it for public use and that they are more concerned to be judged by their peers than with relating the potential of their findings for the life of society. Recognizing and dealing with these insights about the nature of the gap between science and society have, alas, too often been forgotten or overlooked in the many twists and starts that science for the masses has taken in the intervening 150+ years. Wilkinson's points have repeatedly occurence in the numerous attempts in that time to enable Science for All to be the priority goal of school science.

In the years following Wilkinson's lecture, much more was done at the public level than at the school level to provide education in science to the masses. In the nineteenth century, the Mechanics Institutes in Britain and their counterparts elsewhere made lectures on science cheaply available to the public, and these were supplemented by a variety of science-based magazines. In the first half of the twentieth century, a spate of small books on aspects of science appeared, written by leading scientists enthusiastic to share their knowledge. The best-selling book, *Science for the Citizen* by Lancelot Hogben, met and enhanced an obvious public interest that nowadays is further stimulated and met by the natural history and science programs of the BBC and National Geographic.

With respect to school science, there was enthusiasm in England in the 1930s for the teaching of general science, as an alternative or precursor to the teaching of the separate science disciplines, and similar moves occurred in other countries. In each case these alternatives, in due course, languished when it became clear that the new approach was being associated with less academically oriented students and hence carrying less status than the traditional science subjects. As part of the 1960s era of new science curriculum projects, there was also a brief flourishing in pilot form of a Unified Science Education course in the USA and of the Schools Council Integrated Science Project (SCISP) in England that minimized the differences between the disciplinary sciences in favor of more general big scientific ideas, but these failed to become in any way mainstream.

In continental Europe the “didaktik” tradition in education, as compared with the Anglo-American tradition, has more clearly differentiated Wilkinson’s point about the scientific knowledge needed by scientists being different from the scientific knowledge needed by citizens as a whole. However, the specialist teaching of the science disciplines in Europe has militated against their knowledge being brought together in a way that addresses the multidisciplinary realities of science and technology in society.

Science for All next became a widely used slogan in the 1980s reflecting a widespread aspiration for a reform of school science education that would widen the contribution it could make to all students and not just to the minority of future science-based professionals, the primary beneficiaries of the 1960s reforms. The slogan was launched in a number of important national reports, Science for All Americans, Science for All Canadians, and in a UNESCO report, Science for All, generated in its Asia/Pacific Region. Each of these set out a broad brush case for this widening of school science’s target leading to a new set of aims for school science. The Canadian set was the most fulsome with science education being a preparation for the world of work and for moral development as well as the more customary aims of meeting the needs of the science career-oriented students and of the whole student body’s participation in science and technology situations. With the dawn of the twenty-first century, both the world of work (the demand for generic competences) and the ethical challenges (such as global warming, world health, the need for water, etc.) have added new complexities to the teaching and learning of science.

As in the earlier attempts to achieve Science for All, these intentions in the 1980s have also proved difficult to translate into an acceptable and operational curriculum for school science, although a movement to use the trio of the science-technology-society as a frame for school science showed promise for a few years in several countries. It seems as long as there is the expectation that school science will act as a preparation for, and a selection of the small proportion of students who aspire to high-status career courses like medicine and engineering, it will remain difficult to develop a similarly highly regarded and differently designed course of more general science study.

By the 1990s “scientific literacy” had replaced “Science for All” as a slogan, in part to give it a more operational tone and in part to ally science education with the preeminent position, particularly in relation to primary or elementary education, that number literacy and language literacy have always had. In 2007, Douglas Roberts used the new slogan to clarify the issue to which Wilkinson had pointed by defining two visions of scientific literacy: one turned inwards to the sciences themselves and one turned outwards to those real-world situations involving science and technology that we all, as citizens, increasingly encounter. The first vision leads to a curriculum in which what is to be learned is listed in terms of a logical development of separate science disciplines, albeit encouraging interaction of these in interdisciplinary phenomena. The second vision leads to a curriculum that is thematic in structure drawing on whatever disciplinary knowledge is appropriate and building up big scientific ideas and principles.

The task of balancing the science curriculum in terms of these two visions is now evident in recent curriculum documents around the world. The Twenty-First-Century Science Project in England is one example, as is the addition in Australia of "Science as Human Endeavour" as a new strand of science content. The OECD'S PISA project for assessing science learning has also encouraged these endeavours.

Cross-References

- ▶ Curriculum Movements in Science Education
- ▶ Scientific Literacy

Science for Citizenship

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Contemporary science curricula in many countries emphasize the importance of educating a scientifically literate citizen, who is able to participate in debates and decision-making related to the issues societies have to face in which science and technology are involved (e.g., energy resources and consumption, water, food and agriculture, human health, global warming, nanotechnology, information). Better informed democratic participation is the aim of science education. This can be related on one hand to a public distrust of scientific expertise in the context of recent health and environment crises related to science and technology (for instance, mad cow disease, the Chernobyl and Fukushima nuclear accidents, genetically modified food, the impact of genomics on medicine) and on the other hand to a problem in several countries of a decrease in the number of university students in science (particularly in physics). Democratic participation as an aim of science education may serve as an argument for the presence of science education in secondary education, or alternatively it may orient a deep change of science education curricula to meet the needs of youth in today's society. While many agree that an important aim of science education is to enable democratic participation, science education for citizenship is also a formidable task (Levinson 2010).

Legitimate concerns of citizens may be interpreted by some philosophers and sociologists as a symptom of a problematic increasing gap between science and society. From such a perspective, science and society are considered as separate spheres that may interact with each other. Some scientists fear that society's support for science through public funding of research may decrease and, hence, call for urgent action to improve public understanding of science. Science education is considered in this context to have a particularly important role. Science for citizenship is, from this perspective, considered to be a possible way to "reconcile" pupils (as current and future citizens) with science and technology, leading to an argument that scientists should engage in actions oriented towards schools. Depending on the nature of the pedagogical activities, science for citizenship may appear to be a slogan to popularize science or communicate the benefits of science and technology. This slogan aims at making science teaching more attractive while maintaining a tradition of the teaching of science content (and marginalizing knowledge of the nature of science or of history and sociology of science). Other scholars have argued, however, from the critical study of international surveys like PISA and other recent reform efforts, that "science for citizenship" is a renewed expression of an old hegemonic project to impose the values of Western societies upon the world (Carter 2008).

A more commonly held view is that "science for citizenship" invites science educators to engage in a deep reformulation of a school science curriculum that no longer meets the needs, interests, and aspirations of young citizens. If current social and environmental problems are to be solved, they argue, we need a generation of scientifically and politically literate citizens in the context of economic globalization, increasing production, and unlimited expansion that threatens the freedom of individuals, the spiritual well-being of particular societies, and the very future of the planet. To achieve such a goal, some argue that the science curriculum should be oriented towards sociopolitical action (Hodson 2003). From this perspective, science for citizenship implies the democratic participation of citizens in scientific and technological affairs (from public debates, to decision-making on socio-scientific issues, to science and technology research policy).

Within these various perspectives on science for citizenship, different perspectives on the "citizen" are apparent. A citizen may be reduced to a consumer of goods, if scientific literacy is developed in order to equip pupils to become sufficiently aware of science and technology for decision-making about purchases. On the other hand, a citizen may be considered a professional if science for citizenship is focused on work preparation. Or the focus may be on the "average citizen" who has to understand and cope with everyday phenomena and participate in political decision-making on issues that require an understanding of science and technology.

This is also an aim of those who advocate science education approaches such as science-technology-society (STS), science-technology-society-environment (STSE), and the discussion of socio-scientific issues (SSI). It is also closely linked to the vision of scientific literacy which Roberts (2007) names Vision 2.

Cross-References

- ▶ Ecojustice Pedagogy
- ▶ Interests in Science
- ▶ Socioscientific Issues

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Science for Girls

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The underrepresentation of women in science first became a focus in the late 1970s and early 1980s when two bodies of literature – feminist theory and the history of women in science – converged. What emerged was the realization that women in fields of science were not being adequately recognized and women in the process of choosing fields of study were not pursing science careers in ways that were consistent with their numbers or level of achievement.

Inequitable opportunities for girls to participate in science have been documented in schools, in programs outside of school, and even in the differential treatment offered by a parent or guardian at home. Enhanced awareness and interest in addressing the underrepresentation of girls in science led to a variety of programmatic efforts. While examples of gender inequity and stereotyping continue today, apparent in school texts, children's books and movies, classroom experiences, exposure to science toys, and other science-related experiences, there has also been great progress.

Data gathered by a variety of agencies (American Association of University Women 2010; National Science Foundation 2011; Department of Education 2012; National Science Board 2012) now focuses not just on science but on **s**cience, **t**echnology, **e**ngineering, and **m**athematics – often referred to as STEM. This statistical evidence suggests that there is greater equity in school and test performance, as well as class participation in the STEM fields. But even though girls and boys do not differ significantly in math or science performance, boys' confidence and interest in science majors and careers exceeds girls'. Women outnumber men in biology, psychology, and social sciences but are greatly underrepresented in engineering, computer sciences, and physical sciences. In these male-dominated areas, women earn less than 20 % of the bachelor's degrees awarded each year. This underrepresentation of females and minority groups in particular STEM fields remains a troubling issue.

Girls' Learning Preferences

Getting turned-off or pulled away from STEM careers, especially in the fields of physics and engineering, appears to be the result of an intricate web of experiences at home and at school, societal messages through media, toys, games, books, and expectations about what science is and who does it. A growing body of research on identity development posits that an important ingredient to a girl's ultimate engagement in STEM fields is her development of a sense of herself as someone who "does science." Important to note is that the percentages of women and men who are in STEM fields worldwide vary greatly, providing additional evidence that women's pursuit of science is not a capacity issue, but a cultural and/or environmental one.

A powerful strategy for encouraging girls in pursuing science as a hobby, interest, or career has been the development of girl-focused science programs outside of school. Informal settings provide unique opportunities to engage with and connect with science in an inquiry-based manner without the academic requirements of memorization and standardized testing. A strength of informal environments is support for science learning in ways that utilize learning strategies found most effective for girls. These include opportunities to investigate and learn in safe, nurturing environments, offering noncompetitive, nonjudgmental surroundings that often include opportunities for cooperative learning and exploration and activities that are personally relevant, process oriented, and socially impactful. While these experiences may be effective for all children, research suggests that it is these approaches that are particularly critical in engaging girls.

Informal Programs That Support Girls' Science Learning

There have been several hundred girl-focused programs supported by various federal agencies and foundations over the last decades. These programs focus not only on content and inspiring girls to pursue careers in science but also on developing confidence, positive attitudes about science, and a broader understanding of the ways in which one might engage in science learning and practice.

Informal science programs vary widely in their offerings and intended outcomes. Most efforts offer access to STEM learning through a variety of access points or strategies that may include:

- Female scientist role models
- Field trips
- Hands-on activities
- Project-based/inquiry-based opportunities
- Teaching others
- Working within science strong institutions, companies, or programs
- Career awareness and development activities
- Exposure to unique experiences

Activities can be extremely diverse, ranging from programming computers, or building and shooting off rockets, to digging for fossils, conducting a water study, or growing fruit flies.

Settings vary from museums and zoos to afterschool programs, outdoor classrooms, field-based sites, community-based organizations (CBOs), and clubs. Some of these programs last for an afternoon; others run intensively for years. While informal STEM programs may offer exposure to skills and practices, all vary not only in structure and intensity but also in their connection to a larger community of people committed to science and/or girls. The result is outcomes beyond science learning that include improved self-esteem, self-efficacy, and leadership skills.

Recommendations for Encouraging Girls in Science

While research about women's long-term participation in science resulting from participation in informal science programs is modest, there is evidence that informal STEM experiences can be beneficial in supporting and building capabilities, experiences, and confidence in science. Some recommendations to support girls in science include the following (Halpern et al. 2007; Afterschool Alliance 2011; McCreedy and Dierking 2013):

1. Integrating girl-friendly strategies
2. Providing experiences that enhance girls' beliefs about their abilities to participate in and contribute to science
3. Exposing girls to science careers and female role models in ways that illustrate their importance and value so that a career in science is seen as significant, and just as valuable as others, and a place where they could belong
4. Appreciating the benefit of providing multiple access points to science learning and continued support in pursuing and extending stem interests once engaged
5. Offering rich and diverse stem experiences and unique opportunities that expand girls' understanding about what counts as science
6. Providing opportunities that empower girls to take charge, teach others, and learn authentic science skills and practices
7. Integrating math into stem programs in authentic ways that do not position it as a gatekeeper or barrier to all pathways to science
8. Viewing stem as a vehicle for growth, appreciating that stem experiences and youth development can and do go together

Ideally, informal STEM learning experiences for girls, along with experiences they have at home, school, university, and the work place, build upon one another, as well as connect to and reinforce the countless other experiences in a girl's lifetime.

Cross-References

- ▶ Gender
- ▶ Gender-Inclusive Practices
- ▶ Learning Science in Informal Contexts

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Science Kits

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Science kits have grown in popularity in recent years and have been increasingly used in elementary and middle school science instruction. Science kits typically include materials for students to use to do an investigation and instructions for teachers on how to use the kit as well as background information. Kits also may include supplementary materials such as related literature, other investigations, and suggested assessment items. Generally kits are created to be all-inclusive and are designed to be used with minimal preparation time. Most kits focus on a single science topic such as magnets or rocks.

Science Kits and the Curriculum

Early science kits were designed for students to use as take-home experiments that could be done as an extension of classroom instruction or as a family science activity. In the 1960s kits emerged as a tool to help teachers implement inquiry by providing materials and instructions. These kits were followed by longer-term kit programs that were designed to promote the development of inquiry skills by engaging students in experimentation. Science kits have emerged as tools for schools, distance education programs, and home use.

Today extensive kit-based science programs are developed and distributed by school systems, textbook publishers, and science supply companies. Science kits are also often available from institutions such as science centers and museums and are mostly designed for use in schools. These kit programs include a variety of topics and include kits for multiple grade levels. Most of the science kit programs have focused on the elementary grades, but there are now science kits developed specifically for middle and high school science programs.

In some school systems, kits are designed to be used as the science curriculum, but in many cases, kits are used as either a supplement to the curriculum or stand-alone units that can be implemented as needed. The inclusion of materials and directions for investigations is common to nearly every type of science kit. It is common in school systems that use kit-based science programs for kits to be refurbished centrally, thus removing teachers from the burden of locating, storing, or inventorying materials.

Challenges to Using Kits

Although there are distinct advantages for teachers to use kits (materials are provided and there is no need to purchase, store, or inventory materials), these very advantages for individual teachers provide significant challenges for school systems that must purchase kits, resupply the materials, and provide a distribution system for delivery and pickup. The effort for providing and maintaining materials shifts from the level of the teacher (and school) to a central authority. Often this change in responsibility is accompanied by a shift in funding for science from the school to a central school system program.

Kit Effectiveness

In general, research on science kits has shown that kits have a positive influence on teachers' and students' attitudes about science instruction and can promote the use of inquiry in science classes. Kit use has been shown to impact student achievement. Dickerson et al. (2006) examined teachers' use of kits with 2,299 elementary school students in three grades. Schools that used a kit program were compared to schools that did not use kits. Student scores on achievement tests were compared, and for 15 matched school samples, five of the schools that used a kit-based science program had statistically higher scores, and only one of the traditional science program schools had higher achievement.

A study by Jones et al. (2012) of 503 elementary teachers found that teachers' instructional strategies, classroom practices, and assessment varied according to how frequently teachers used science kits. Jones et al. reported that teachers who used kits most often were more likely to have their students design experiments and collect and analyze data. In addition, the teachers who used kits often were more likely to use small-group learning and alternative forms of assessment such as portfolios and notebooks. Teachers who used kits less often tended to report more traditional types of instruction, including having students practice for standardized tests.

Like other forms of curricular innovation, kits are most effective when they are aligned with teachers' existing beliefs and practices. Rennie et al. (2010) maintain that teachers need deep content and pedagogical knowledge to effectively implement inquiry with kits. For school systems that move to using kit-based curricular programs, these differences in teachers' experiences, competencies, and beliefs must be taken into account when making this kind of systemic change. But even with the challenges of implementing a science kit-based curriculum, schools often report improvement in teachers' confidence in teaching science as well as an increase in the use of inquiry.

Cross-References

- ► Science Community Outreach
- ► Science Museum Outreach

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Science Museum Outreach

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As long ago as 2001, the director of the Science Museum of Virginia, Richmond, USA, in an article for *ASTC Dimensions*, described his institution as a "community powerhouse." He rightly pointed out that science museums and science centers have many roles to play in serving their communities, many of which can only be fulfilled through "outreach."

Outreach is capable of many definitions, but one which applies well here is "any systematic effort to provide unsolicited and predefined help to groups or individuals deemed to need it." This is not a new form of education: as early as 1891, the "science demonstrator" to the Birmingham School Board in England had adopted an outreach program which circulated science teaching equipment and samples to schools in a handcart. The motivation, then as now, was to provide resources where they were most needed – economically and efficiently and in a timely manner. Science museums and science centers embraced outreach from their early years. Museum loans of natural history specimens to schools were common during the twentieth century, and early-established science centers like the Ontario Science Centre were taking programs to remote areas (and, in the specific case of OSC, education programs for students and teachers in the schools for Canadian Forces based in Germany).

In the succeeding years, the reasons for conducting science museum outreach have become more subtle. A process which may have begun as a profile-building exercise or for meeting a resource deficit has evolved into a developed sense of responsibility for promoting community engagement – in ways that are

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"This article was written in 2012."

similarly practiced by orchestras, football teams, opera houses, and theater companies. Such engagement may be socially motivated (e.g., in using outreach programs to promote social cohesion) or driven by a wish to take science directly to the public. An important element in science museum outreach activity is engagement with the formal education system through visits to primary and, less frequently, to secondary high schools.

Examples from around the world are now chosen to illustrate the various methods and motivations for delivering outreach programs from science museums and science centers. The broadcast media and online activity are excluded from this account, as they are treated separately elsewhere.

The Shell Questacon Science Circus claims to be "recognised as the most extensive and longest running touring science centre outreach program in the world." Using a large vehicle and a team of presenters, it offers school shows, professional development for teachers, a traveling science center for the community, and extension activities for senior high school students. This is a model which has been adopted worldwide and indeed was being used, e.g., by the Ontario Science Centre, as early as 1971. The Australian science circus has another purpose; however, it is a core component of the training of future science communication professionals who are following a Master's program at the Australian National University, Canberra. It has also undertaken an "ambassadorial" visit to China.

Science on the move, using vehicles ranging in size from caravans to tractor-hauled multi-wheel trailers can now be found on every continent. Heureka, the Finnish science center, has even offered science shows on cruise ships in the Baltic. PROMUSIT is the traveling museum program from MCT-PUCRS, the interactive Museum of Science and Technology run by the Catholic University of Rio Grande do Sul, Brazil. In operation since 2001, it carries 70 exhibits, a collection of interactive kits, and provides an air-conditioned auditorium within the vehicle. The DESTINY program in North Carolina, USA, originating in 2000, has two 24-place mobile laboratories operated by the Morehead Planetarium and Science Center. The MysteriX science truck from the Technopolis science center in Mechelen, Belgium, has been touring Flanders since 1998. It converts to a mobile laboratory with a themed program in which students have to solve a series of problems within a fixed time to prevent the world from being extinguished by "a mystery virus." In Mauritius, the Rajiv Gandhi Science Centre's "Caravane de la Science" provides interactive science demonstrations, exhibits, and film shows "to explain science concepts…and encourage critical thinking," while their science bus contains 24 interactive exhibits on the theme "We are one" – regardless of color, caste, or race, our bodily organs perform the same functions.

This last example hints at the importance throughout the world of using science outreach to support social cohesion and well-being. Science centers and other informal learning environments are increasingly concerning themselves with socio-scientific issues, sometimes with the aim of influencing attitudes and behavior. A recent study investigated the effects of an HIV-AIDS science theater presentation on the behavioral intentions of 697 South African students, a population facing extreme HIV risk.

Ecsite's PLACES project moves the sociopolitical goal to a policy-making level. Its aim is "to enhance the three-way conversation between science, policy makers, and society", and many European science centers are involved in its "Science Cities Workshops."

Family workshops conducted by London's Science Museum in three different prisons have helped in the difficult process of consolidating relationships between prisoners and their families. Thinktank in Birmingham, UK, has undertaken a series of programs with elderly residents in care homes, in some cases supporting those with dementia as well as age-related physical disability.

Such programs have been described as "citizen science," ultimately enhancing democracy as well as social and economic development, along with fulfillment for the individual.

Transport options must be appropriate to circumstance, and the Manthan Science Center, India, used a camel-drawn cart laden with posters and solar viewers for its participation in the "100 h of Astronomy" program of International Astronomy Year 2009. Elsewhere in the same country, it was possible in 2012 to visit the Science Express Train, with its exhibition on biodiversity and conservation, the "joy of science" hands-on lab, and a teacher-training facility. In Bogotá, Colombia, the Maloka science center has a Cycle Science program in which bicycles equipped with hands-on science activities tour the city streets on Sundays. It also reaches out to municipalities without roads or land access, using boats fitted out as floating classrooms with satellite internet connection.

The principle of the "circus comes to town" is widely adopted by science centers, with many examples of touring programs that settle for a day or two in places where families are generally to be found: shopping malls (an example from 2001 was Science on the Mall: large-scale interactive exhibits from SciTech, Aurora, Illinois), parks (e.g., the Science Picnics in Warsaw – "Europe's largest outdoor science popularization event" organized jointly by the Copernicus Science Centre and Polish Radio – and a similar event in Lausanne from the History of Science Museum), and beaches (e.g., Techniquest's 1996 PanTecnicon program on the beaches of Wales). The product of a science center background is the nonverbal theater show from "Science Made Simple" called Visualise, an extravaganza of visually exciting science phenomena, accompanied by mime and music. Activities of this kind are also offered by science centers to the growing number of "science festivals" that have blossomed around the world. EUSEA (mainly Europe) and the Science Festival Alliance (mainly the USA) are two coordinating bodies with an international remit.

In Brazil, São Paulo's "Science Station" reaches out to street children in the Lapa quarter of the city with Project Clicar, an ICT-based project which provides youngsters with their only address: an email one. Meanwhile in California, the Cal State Long Beach Mobile Science Museum visits children of homeless Long Beach families as part of a science education camp. In Mexico City, Universum works with the "Office for Attention to Vulnerable Populations" to bring health topics and the underlying science to disadvantage people in educational and disability care organizations. The Boston Children's Museum takes family learning opportunities to low-income public housing developments through its Go Kids program.

Integrating traditional knowledge and science, The Bishop Museum in Hawaii reaches out to underserved schools throughout the Hawaiian islands through its program "All Together Now," which aims to integrate the science with cultural stories, combining Western science with relevant cultural knowledge and practice. In Montana, a program with similar intent reaches out to the indigenous American Indians through the Blackfeet Native Science Field Center. In Western Australia, Scitech from Perth has, since 2007, visited every remote Aboriginal community every other year with student workshops, teacher development materials, and resource kits. The program, which can extend more than 3,000 km from the home base, involves significant staff training in cultural competencies and safety matters.

Sometimes, outreach is only "across the street" – the Ontario Science Centre's Flemingdon Park project – or aims to capture audiences who may be frightened of science: the Science ABC sessions from Science Oxford are for everyone who has never studied science or who has forgotten what they ever knew! At other times, it reaches out over considerable distances: OMSI, the science center in Portland, Oregon, has an award-winning program which it operates with library partners to provide underserved rural communities with access to science workshops. The Oak Hammock Marsh Interpretive Centre in Manitoba has a Wetlands Outreach program which covers a vast geographic area across three Canadian provinces – and Scitech in Perth operates across many thousands of kilometers in Western Australia.

Supporting schools is perhaps the most common motivation for science museum outreach programs. Examples divide into two kinds:

those which enrich or complement an already well-established curriculum, bringing unusual resources and/or specialized expertise to the classroom, and those which compensate for deficits in equipment or pedagogy. In simplest terms, these two approaches are found in the richer and poorer countries of the world, respectively, but the distinction is by no means clear-cut.

The Unizul Science Centre in Richards Bay, South Africa, offers various outreach programs, one of which is explicitly “compensatory.” Many high schools are struggling with large classes, limited equipment, and poorly qualified staff. The science center offers workshops at seven different rural locations to demonstrate practical work to matriculating students – work which is examined but seldom performed.

Of the “complementary” programs, there are many to choose from. Those interested in well-described examples could look at the Classroom and Assembly programs from the Science Center of Iowa, Des Moines, USA; the Bodyworks program from the Glasgow Science Centre, Scotland, UK; the Reach the Heights program from Techniquest, Wales, UK; Smart Moves, Science Play, and Maths Squad from Questacon, Canberra, Australia; Scientists on Tour from the Dundee Science Centre, Scotland, UK; Astronomy on Wheels and the Educator Loan Kit Program from the Fort Worth Museum of Science and History, Texas, USA; OMSI’s widely dispersed “traveling programs” for schools and teachers; and the Talk Science professional development program for teachers from the Science Museum, London. Commitment to lifelong learning, involving both schools and communities, is often espoused by science centers, a notable example being the Exploratorium in San Francisco, USA.

Conclusion

Most science museums and science centers succeed in maintaining a “baseline” offering of outreach programs, normally including:

- Support for schools’ classes, often with explicit built-in professional development for teachers
- Community projects intended to maintain the profile of the providing institution, often partnered with other family-friendly events
- Simple traveling programs (e.g., small-scale loan exhibits for classroom use, portable planetaria)
- Lecture programs, science cafés, and other “dialogue” style events

The more challenging and exciting examples of outreach are necessarily more resource-intensive and often tied to fixed-term grant funding, whether of a capital or revenue nature. Major assets such as sophisticated vehicles become increasingly expensive to maintain and operate and generally have a limited life engaging with the public. Programs focused on hard-to-reach audiences, whether for cultural or geographic reasons, require dedication on the part of the provider – both to the delivery and to the generation of recurrent funds for maintaining the operation.

Evaluating the impact of all this work offers the same challenges as the wider effort to understand the power of informal learning environments. All too often, the evidence for learning cannot be captured when the learner is exposed to the experience, and indeed, it is common for this evidence to become apparent only when a new context arises where the learner makes a connection with the earlier experience. Numerous individual outreach projects have been evaluated for their impact, with varying degrees of robustness, but no general study of this area appears to exist.

A further complication in assessing impact arises when an outreach project – as frequently occurs – has an evolving set of objectives during the course of its lifetime. Techniquest’s “Comm Quest” project began as a public showcase for interactive science in partnership with the Commonwealth Secretariat at the Commonwealth Heads of Government meeting in Durban, South Africa in 1999. It then toured the country as an educational resource, with excursions into public domains (e.g., shopping malls), and a dozen years later, it was still being traveled – under the name SciQuest – as an interactive science exhibition for communities.

Science outreach is widely practiced by research institutes, universities, medical institutions, and bodies like NASA which have a major responsibility for the achievement of a nation's technological ambitions. Very frequently, they operate in partnership with science museums and science centers, seeing them either as delivery partners or as gatekeepers to the formal education system. Most frequently the motivation is to do with building the public's awareness and appreciation of medical, scientific, and technological research. These programs, too, are building bricks in the "community powerhouse."

Cross-References

- ▶ Café Scientifique
- ▶ Citizen Science
- ▶ Learning Science in Informal Contexts
- ▶ Museums
- ▶ Public Engagement in Science
- ▶ Science Circus
- ▶ Science Community Outreach
- ▶ Science Festivals

Science Olympiad

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The Olympiads are like the Olympics, but for academics, not sports. Unlike the Olympics which are held every 4 years, the Olympiads are annual events held in a different country each year. Further, the participation is limited to preuniversity students. These annual international Olympiads are held in a number of subjects: physics, chemistry, biology, junior science, astronomy and astrophysics, and mathematics, among others.

The Olympiads were initiated by teachers and academicians in USSR and the erstwhile east European nations about 50 years ago, in the late 1950s and 1960s. The Mathematics Olympiad was the first to be organized in 1959. Physics and Chemistry followed a decade later, in 1967 and 1968, respectively. Each of these began with half a dozen or less east European nations bringing together about five of their brightest students to a single location and posing a series of challenging tests. This trend has continued with the students being accompanied by two teachers who are called leaders and sometimes an additional observer teacher.

The theoretical tests are spare in nature. The number of questions is about 3–5 and the student is given 5 h to attempt them. Either one or two experimental tasks are assigned, and once again, the student is given ample time to complete them. The purpose is to test the student's creativity and innovation. The tests are designed by the host country. The leaders form the "jury" and vet the questions before these are presented to the students. To ensure confidentiality the leaders and the students stay in separate locations and are not allowed to meet during the testing period. The leaders are provided with the photocopies of their students' answer scripts and grade them independently of the host country. They are given an opportunity to discuss their evaluation vis-à-vis the host country's evaluation team during a moderation session. In other words the tests are ability and not speed tests and the process of evaluation is made as fair as possible.

Students who do well are awarded medals. Usually the top 10 % of the students are awarded gold medals, the next 12–15 % are given silver medals, and then those in the next 15 % slot are given bronze medals. In some of the older Olympiads, there is an additional category called honorable mention for those who did reasonably well but did not bag medals. The detailed scheme for each Olympiad is quite involved and the above percentages for medals are approximate. The overriding concern is to promote goodwill, and hence, there is no official ranking of nations.

The Olympiads have impacted the educational curricula of several nations. Numerous textbooks and problem books based on national selection tests have been published. Several of the problems have been published in leading peer-reviewed science journals. Special journals devoted to problems and competitions are currently published. Teachers and resource persons associated with the Olympiads have been invited to serve on panels to design school tests and to improve the course content.

There has been a steady increase in the number of Olympiads. The Biology Olympiad was started in 1990, the Astronomy and Astrophysics Olympiad in 2007, the Informatics in 1989, and the Earth Science Olympiad in 2007, to name a few. Regional Olympiads have gained popularity. The Asian Physics Olympiad was started in 1999 and now has over 20 participating nations. Many of these are "official" in the sense that there are carefully laid out rules and statutes and that the host nation routes its invitation through the nodal agency responsible for the selection of the team via a high-ranking government functionary, such as the minister of education. In contrast there are a host of private Olympiads.

The Olympiads are held in different countries from year to year. They have grown in size. The Mathematics and Physics Olympiads boast of close to a 100 nations. Each participating country pays a modest "entry" fee and pays for its travel. The expenses for the stay and excursions are borne by the host country. The Olympiad serves as an occasion to showcase the culture and educational strength of the host nation to teenage students who would become the future scientific leaders of their nation. Every attempt is made to maintain bonhomie, cheer, and goodwill. The Science Olympiads are a celebration of the best in preuniversity science.

Listed below are some helpful Olympiad websites:

www.Olympiads.hbcse.tifr.res.in for Olympiads
ipho.phy.ntnu.edu.tw, www.jyu.fi/ipho for International Physics Olympiad
www.icho.sk for International Chemistry Olympiad
www.ibo-info.org for International Biology Olympiad
www.ioaa2010.cn for International Olympiad on Astronomy and Astrophysics
www.ijso-official.org for International Junior Science Olympiad
www.imo-official.org/ for International Mathematical Olympiad

Cross-References

- ▶ Science Fairs

Science Studies

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Keywords

Culture; NOS; Philosophy of science; Science wars; Social sciences; Sociology of scientific knowledge (SSK); STS

Science studies is an area of scholarship devoted to the understanding of science and its operations as well as its interactions with society. Though its borders are far from sharply defined, science studies is generally understood to encompass work done in any of the fields of history, philosophy, sociology, and anthropology of the natural sciences. Such work aims to understand, among other things, the conceptual, epistemological, social, and cultural aspects of the sciences and the communities of practitioners that pursue scientific research. These studies make up the core of the field. Other approaches include disciplinary work drawing from cognitive psychology, cultural and feminist studies, and other research and theoretical traditions. Scholars working within these various fields are most frequently interested in developing understandings of the natural sciences (e.g., physics, chemistry, biology, geology) but have also focused their attention on newer interdisciplinary fields such as biotechnology, biomedicine, computer and information studies, and technology itself as well as social science fields such as economics (Fuller 2005; Hess 1997; Sismondo 2009).

The field is sometimes referred to as "science and technology studies" in which case it goes by the acronym STS. This version explicitly adds technology to the mix, a move that not only places technology on equal footing with science but also acknowledges the recent trend by some scholars in the field to see science and technology as indistinct, recognizing that we have, in fact, entered a period where "technoscience" is perhaps a better description of what those engaged in scientific research actually produce. STS also serves, in some circles, as shorthand for "science and technology in society." Originally this denoted a distinctive approach in the field that sought to explore more closely the relationship between science and society (particularly to make science more accountable to public interests) in contrast to the epistemological and sociological practices of science in and of itself (Sismondo 2009). In the context of science education, this usage evokes the STS curricular movement of the 1970s and 1980s that situated science in the context of contemporary social issues, especially those related to the environment.

One of the primary goals of science studies, put simply, is to explain how science as an activity *works* using the methods of the social sciences and philosophy. The first systematic efforts to develop some extrascientific understanding of science in this way came in the field of philosophy where questions about the essence of knowledge extend back hundreds of years. The philosophers were later joined by historians, who sought to document the progress of scientific thought. While such efforts go back to the emergence of science as a clearly identifiable community of practice in the early 1800s, more formal efforts to chronicle the historical development of science, particularly with the aim of demonstrating its normative structure, came in the middle decades of the nineteenth century. From the mid-nineteenth century to the middle of the twentieth century, the history and philosophy of science stood alone as fields devoted to the understanding of science as a human activity.

It was only during the 1960s that science studies coalesced into an identifiable field. Important foundational work came from the sociologist Robert Merton (1910–2003), who articulated an early view of the social and cultural norms of science, and Ludwig Fleck (1896–1961). The work of Thomas Kuhn (1922–1996), however, particularly his seminal book *The Structure of Scientific Revolutions* (1962), was the catalyst that gave rise to science studies in something close to its current form. Kuhn's book, which offered what many saw as a radical account of scientific change over time, combined with the heightened attention to the role of science in society that came as a result of the massive government investment in scientific research during World War II and throughout the postwar period to shine a light on the functions of science. The new public investment in science and growing influence of technocratic government initiatives and outlooks led to the founding of new, interdisciplinary science studies programs in the United Kingdom that were originally designed to ease the transition to a society newly infused with high levels of science and technology (Edge 1995).

Although originally intended to engage in science education that would promote a humanized form of science more attuned to the needs of society, the new programs in the United Kingdom soon turned to more academic questions surrounding the very operations of science and the manner in which it generated new knowledge about the natural world. The most famous of these was the science studies program at Edinburgh University. Scholars in this program developed what came to be called the sociology of scientific knowledge (SSK) approach that called into question the authority and objectivity of science. Taking their cue from Kuhn's assertion in *Structure* that revolutionary changes in science occur by means other than rational consideration of empirical evidence, Edinburgh scholars such as Barry Barnes and David Bloor argued that the emergence of scientific theories is significantly influenced by the social and cultural commitments to which scientists adhere (Edge 1995).

It was this work that was largely responsible for what many referred to as the "science wars," which, in simple outline, consisted of sociologically inclined science studies scholars on one side who sought to problematize the certainty and authority that institutional science sought to project and scientists (largely) on the other side who resisted this critical examination of their enterprise and endeavored to expose what they believed was less-than-rigorous intellectual work. This genre of science studies, they argued, betrayed a lack of scientific understanding and ultimately demonstrated the vacuous nature of their assertions. A significant amount of the conflict centered on the "Sokal hoax" of 1996. The "science wars" largely passed out of attention not long after the turn of the twenty-first century. Science studies work, however, continues in all the fields mentioned above. Among the subsequent threads of scholarship still being pursued are laboratory studies that seek to carefully document the day-to-day production of knowledge, cultural histories of various disciplinary fields, and philosophical analyses that seek to understand the epistemological practices of science in its natural settings (Fuller 2005; Zammito 2004).

Research in science education and science studies has intersected in a number of ways beginning in the 1970s and 1980s. Two of the most prominent areas of contact have been related to science curriculum and pedagogical practice. With respect to curriculum, there has been, perhaps, no more sustained research focus than that dedicated to conceptualizing some view of what many have called the "nature of science" and incorporating it into the school curriculum. Work in this vein goes back at least to the World War II era with Harvard president James Conant's efforts to teach about the nature and process of science to Harvard undergraduates in the 1940s. At the precollege level, researchers following the recommendations of various national policy documents have similarly sought to capture the essence of science in order to place it in the curriculum with the belief that some understanding of the nature and process of science is key to a meaningful and socially relevant understanding of science. Although there appears to be consensus on the importance of understanding something about science and how it works, the accuracy and usefulness of the particular curricular portrayals of science advocated have been debated. Insights from the science studies literature have been central to these ongoing discussions.

Scholarship from science studies has led to pedagogical experimentation as well. Recent work on seeing science as a practice consisting of discipline-specific conceptual frameworks, specialized vocabulary, norms of argumentation, standards of evidence, representational tools, and so on has prompted science education researchers to examine the ways classroom instruction might be tuned to simulate certain aspects of scientific practice. Research on student modeling and argumentation are two prominent areas of such work. The history of science (another domain within science studies) has been used as a resource for alternatives to traditional instruction in science as well. Historical case studies or narrative accounts of scientific advance have long held out promise of productively engaging students through a more humanistic approach to science teaching, although the potential of this approach to scale up has not yet been demonstrated.

Beyond the sphere of the school science classroom, science education researchers have explored questions of scientific literacy or how citizens engage with science in their daily lives using insights from various science studies fields. Conversely, science studies scholars – particularly those in the history of science – have begun to examine how pedagogical practices and texts have emerged and functioned in the reproduction of various communities of scientific practice through history. Such work highlights the value and productivity of the growing mutual recognition of the science studies and science education research communities.

Cross-References

- ▶ Action and Science Learning
- ▶ History of Science
- ▶ NOS, Measurement of
- ▶ NOS: Cultural Perspectives

- ▶ Paradigm
- ▶ Sociology of Science
- ▶ Socioscientific Issues

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Science Teacher Education

- ▶ Primary/Elementary Science Teacher Education

Science Teacher Education in Mainland China

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Keywords

Science Education in the Non-West

Introduction

As in many other countries, the science teacher education system in mainland China is a part of the teacher education system of the country. Chinese science teacher education system has undergone tremendous transformation and change since its advent in the early twentieth century, from first transplanting foreign teacher education systems one after another, then through the process of indigenization, to finally forming "the Chinese model of (science) teacher education" (Li 2012, p. 417) with distinguishing features of its own. Today, Chinese science teacher education is very much *sui generis* in that on the one hand it has adopted and indigenized both Anglo-American elements and Continental European elements, including Japanese and Russian influences, and in that on the other hand it has inherited "Confucian epistemology and pragmatism" (Li 2012, p. 417).

In this entry, I first present a historical context in which I briefly describe how Chinese science teacher education system was initially in place. Then, I provide a detailed discussion of the reform and current state of Chinese science teacher education, followed by particular consideration of elementary science teacher education and then secondary science teacher education. Next, I highlight some problems and/or challenges that have arisen in the new millennium that have faced Chinese science teacher education in mainland China. Finally, I conclude with a summary, characterization, and conceptualization of Chinese science teacher education.

Historical Context

In ancient China, there were both public (official) and private schooling systems with teachers transmitting Chinese culture for more than 4,000 years without a break. However, there had been no specialized teacher education system in China until around the turn of the twentieth century when the Western teacher education system was transplanted into China via copying the then Japanese teacher education system (which in turn mainly emulated those of Germany and France at that time).

According to Li (2012), a noted researcher on the Chinese history of education, now working with the Chinese University of Hong Kong, the modern Chinese (science) teacher education system has gone through four stages: (1) establishment (1897–1911), (2) institutionalization (1912–1949), (3) reinstitutionalization (1949–1993), and (4) professionalization (1993–present). During the first stage and the first decade of the second stage, Chinese science teacher education was heavily influenced by Japanese science teacher education in terms of system and program and by taking in pedagogical ideas and theories from Germany, especially Herbart and Herbartianism. Thus in preparing school teachers of science, student teachers would study Herbartian pedagogics (including didactics or Didaktik), educational psychology, and subject didactics (Fachdidaktik), the trio core courses in pedagogical studies of teacher education programs that have since set the tone for and had a lasting impact on Chinese science teacher education until today.

The first institute for training school science teachers, *Nanyang Gongxue*, was founded in 1897 in Shanghai. *Nanyang Gongxue* (the forerunner of Jiaotong Universities in Shanghai and four other cities in mainland China and one in Xinzhu, Taiwan) consisted of four schools: a normal (i.e., teacher training) school, an affiliated elementary school, a secondary school, and a college of higher learning. Following *Nanyang Gongxue*, in 1902 several independent normal schools were established in Wuhan, Hubei province; in Nantong, Jiangsu province; and particularly in Beijing, where, what was called the "Institute for Normal Education" (later to become Beijing Normal University) was added to the newly established Peking University (*Jingshi Daxuetang*). Peking University, the first modern national university in China, had been founded in 1898 by the government of the late Qing dynasty (Li 2012).

These newly founded normal schools across the country and the Institute for Normal Education within Peking University (*Jingshi Daxuetang*) laid the foundation for establishing a national system of teacher education. Thus, in 1902 and 1903, the government of the late Qing dynasty promulgated the first national educational legislation, thereby creating a modern school system based on the model borrowed from Japan. According to the newly promulgated legislation (*Guimao Xuezhi*) of 1903, every county or prefecture should open a junior normal school and every province should open a senior normal school, in order to train teachers for local elementary and secondary schools, respectively (Li 2012). These normal schools were completely transplanted from Japan in respect of their structures, contents, and even the style of school buildings.

Beginning in the early 1920s during the second stage of institutionalization (1912–1949), China began to turn to the USA for a model of education in general and of science teacher education in particular. This was partly because of Japan's aggression to China, which aroused strong feelings among Chinese people against everything Japanese and partly because a large group of US-educated Chinese scholars returned to work in Chinese universities and government agencies and came to dominate Chinese educational circles. It should also be noted that US emerging educational sciences, including curriculum theories and science education research, especially John Dewey's modern theory of education as opposed to the so-called traditional theory of Herbart, attracted many Chinese educators at that time. As a result of these factors, China finally jettisoned the school system that was copied from Japan in 1922, and in its stead introduced a new school system, a 6-3-3-4 system, which was modeled on the US school system. For the following three decades from the early 1920s to the late 1940s, Chinese science teacher education was likewise modeled on the US science teacher education. In correspondence with this, the textbooks of science methods courses in Chinese teacher education programs at colleges and universities at that time were full of US educational ideas and theories, although the titles of such textbooks were still *Jiaoxuefa* (i.e., Didactics) in Chinese, as before.

After the Communist Party of China took power in 1949, during the first decade of the third stage of reinstitutionalization (1949–1993), there was another dramatic shift in education, including science teacher education. This time China sided with the Soviet Union in the socialist camp. As the ideology of the state changed, so did the teacher education system, the dominant pedagogy, and science education programs as well. In terms of the science teacher education system, in 1952 the Chinese communist government issued a policy of restructuring higher education throughout mainland China, and under this policy, a closed, independent teacher education system modeled on the Soviet system was established. All primary school teachers were trained in closed, independent normal schools, who only studied some high school level science courses. All secondary science teachers were prepared by closed, independent normal colleges and universities, with student teachers who would be teaching in junior high being trained in 2–3-year normal colleges, while student teachers who would be to teach in senior high being trained in 4-year normal colleges and universities. In this system of science teacher education, secondary (both junior and senior) science teachers were trained in separate departments of the normal colleges and universities, such as the department of physics, department of chemistry, and department of biology. In this way, for example, a student teacher of physics education had to study physics courses exclusively for 4 years in addition to courses on politics, physical education, foreign languages, and, of course, pedagogical studies. This rigid structure of science teacher education has remained basically unchanged until today, although the whole system of science teacher education has become more open and flexible, as described in the following sections.

Reform and Current State in Science Teacher Education

Reform in Science Teacher Education

Since the start of the fourth stage of professionalization (1993–present) mentioned above, science teacher education has witnessed a major transformation again as the Chinese government began to "embrace a sweeping wave of neo-liberal ideology, e.g., marketization, privatization, and decentralization" (Li 2012) in 1993. This shift in policy has effected considerable change in the (science) teacher education system in the following respects.

First of all, the Law of Teachers of the People's Republic of China, the first such law in mainland China since 1949, was enacted in 1993, signaling a new era of teacher education reform. The law regulates the legal rights and responsibilities of teachers as professionals and mandates a national teacher certification system.

Second, the Chinese government restructured the (science) teacher education system by introducing a mechanism of competitiveness in conducting teacher education, that is, entailing a teacher education system that is chiefly reliant on independent normal colleges and universities while allowing comprehensive universities to develop teacher education programs. Meanwhile, within the normal colleges and universities, teacher education programs and non-teacher education programs go hand in hand, thus breaking the closed teacher education system that originated from the Soviet Union.

Third, two new science teacher education programs have been initiated since the 2000s. One is an undergraduate science teacher education program that aims to prepare integrated science teachers for primary school and junior high school as the current new science education reform dictates. At the time of writing (2013), there are 65 colleges and universities that provide such a program. The second new science teacher education program is intended for practicing science teachers as well as for newly graduated bachelor degree holders who are encouraged to pursue a master's degree program in science teaching and even a DEd program in science teaching, in order to enhance science teachers' status and level of professionalization.

And finally, a discussion of the change that has arisen in science teacher education research and development is in order here. As indicated above, science teacher education research and development in mainland China takes the form of developing subject didactics of science disciplines, such as didactics of physics, didactics of chemistry, and didactics of biology, which is congruent with subject specialization in school science teaching. This is a tradition formed in the early 1900s when China introduced German pedagogics and didactics into the pedagogical courses of teacher education and reinforced later in the 1950s when Soviet pedagogy and didactics were introduced again. Therefore, most science teacher educators in colleges and universities call themselves didacticians of physics or chemistry or biology (Ding 2013). Similarly, most of them identify themselves with their subject associations of science subjects, such as the Association of Physics Didactics, rather than the newly established National Association for Science Education founded in 2009.

However, in respect of the research and development of subject didactics of science in mainland China, a new trend has occurred over the past decade in that didactics has met curriculum studies and the two have merged and been integrated to become a new hybrid pedagogical discipline for science teacher education. This situation has happened in the context of the new curriculum reform that began around the turn of the new millennium when curriculum studies were reintroduced from the USA in the 1990s. Thus curriculum studies since have flourished and developed significantly, and this has paved the way for some didacticians of physics, of chemistry, and of biology to take ideas from curriculum studies into textbooks of subject didactics of sciences intended for prospective and in-service teachers of science. Correspondently such textbooks more and more have taken the titles of "curriculum and didactics of physics" (of chemistry, of biology, and even of science), a newly formed characteristic of science teacher education less seen in other countries.

Elementary Science Teacher Education

Like elementary science, elementary science teacher education has had a long past but a short history in China, as is the case in many other countries. Before 2000, elementary science was called "nature" (*Ziran*) as one of the auxiliary subjects in elementary schools and was generally taught by nonspecialist teachers with a tenuous background in science. As a matter of fact, "nature" was on the school timetable but not taught in many schools, especially in rural primary schools. It depended on whether the school principal placed importance to the subject or not. This was the case mainly because elementary science teachers were not specially trained, although some of them might have gained good in-service training while in teaching. For example, in the late 1970s and throughout the 1980s, Brenda Lansdown (1904–1990), a Harvard professor of science education specializing in primary science, came to China for academic visits many times and gave several workshops on primary science teaching in Beijing and other cities. This prepared a large cohort of primary science teachers from across the country who have become specialist primary science teachers and even today continues to have an impact on the professional development of primary science teachers.

Around the new millennium, the science curriculum reform for the 9-year compulsory schooling decided that "primary science" in place of "nature" as a required subject would be taught from grade 3 to grade 6 in all primary schools. Since then many normal colleges and universities have begun to provide 4-year teacher education programs for primary schools as demands for the qualifications of primary school teachers rise. In these teacher education programs, some of the student teachers select to study more science courses so that they will serve as specialist primary science teachers. This is the case especially in metropolitan cities such as Beijing and Shanghai, as well as provincial capitals and coastal cities. As a result, more and more specialist primary science teachers are prepared by primary science teacher education programs in colleges and universities, although it should be acknowledged that there are many 2–3-year local (normal) colleges still turning out elementary teachers who receive less training in science.

The current science curriculum reforms have also provided a new impetus for the professional development of primary science teachers. Primary science teachers in mainland China consist of two cohorts, with one being specialist science teachers who have stood out as excellent primary science teachers or graduated recently from elementary science teacher education programs in normal colleges or universities and the other being nonspecialists who teach other subjects like mathematics as well as science. So at school level, the specialist primary science teachers may serve as science coordinators helping other teachers improve their science teaching, while at the district, county, and/or municipal levels, some of the outstanding specialist science teachers are selected as science teaching researchers (*Jiaoyanyuan*), whose tasks are to provide in-service training or professional development for primary science teachers.

Secondary Science Teacher Education

Preservice Science Teacher Education for Secondary School. In secondary schools, grades 7–9 are junior high school and grades 10–12 senior high. Except in Zhejiang province and in Shanghai where school science in junior high schools has been taught as an integrated subject since the mid-1990s, subject-based science subjects, i.e., physics, chemistry, biology, and partly geography (natural geography), are taught by different subject teachers. In senior high schools, science is always taught as separate science subjects by different subject teachers. Under this circumstance, preservice science teacher education programs in colleges and universities are conducted in separate departments (or colleges/schools) of sciences in collaboration with the department (or college/school) of education, a tradition that dates back at least to the 1950s when China restructured (science) teacher education system patterned after that of the Soviet Union. For example, all student teachers in physics study in the department of physics, while all student teachers in chemistry study in the department of chemistry, and so on. The departments of physics or chemistry provide subject-based science courses and subject didactics courses (didactics of physics, didactics of chemistry, etc.), while the department of education gives other courses on pedagogical studies, including pedagogics, psychology of education, and educational technology. In many cases, both junior and senior high school science teachers are prepared by 4-year teacher education programs, conferring BSc on graduates. But in some rural areas, junior high school science teachers usually receive 2–3 years college education in local normal colleges, as was the case for all junior high school science teachers before 2000.

Over the past decade or more, preservice science teacher education for secondary schools in mainland China has seen new trends. This is partly as a result of the expansion in enrollments of postgraduate education and partly due to the difficulty of employment for some of master's degree students in science. First of all, some postgraduate students with a master's degree in science are encouraged to work as science teachers, and they have come to form a new cadre of school science teachers, especially in what are so-called model high schools (*Shifan Gaozhong*) in towns and cities throughout the country. Second, some outstanding high schools in metropolitan cities such as Beijing, Shanghai, and others have recently even attracted PhDs in science or in science education to their teaching force. Third, in both undergraduate and postgraduate science teacher education programs, some of the student teachers are offered the opportunities to study half a year or 1 year as exchange students in the universities of industrialized countries on government or interuniversity scholarships, thus facilitating the internationalization of science teacher education for mainland China. Hopefully, there is every reason to expect that these new trends in preservice science teacher education will improve the quality of science teacher education significantly.

Professional Development of Secondary Science Teachers. In-service training/education or professional development for teachers of science (and other subjects) also has a significant place in China. It is also unique in that while it is rooted in both foreign theories and practices which have been indigenized, it is simultaneously predicated on Chinese traditions and experiences.

To start with, as there is only a short period of time (6–10 weeks) devoted to professional experience or practicum teaching in schools for preservice student teachers, beginning science teachers in mainland China usually have an induction period of 1 or 2 years in schools where they are employed to work, which is the so-called mentoring practice on the job. During this period, beginning science teachers are assigned to work with experienced teachers as dyads, thus forming a relationship of master and apprentice. This kind of "cognitive apprenticeship" is a very effective experience of learning to teach for beginning science teachers, because experienced teachers as senior people with wisdom are highly respected in the Confucian culture.

Secondly, the established system of the teaching researcher (*Jiaoyanyuan*, hereafter referred to as *JYY*) has been in place since the mid-twentieth century and is a significant feature of professional development. Who is a teaching researcher or *JYY*, and what does he or she do in the professional development for science teachers? (Ding 2013)

A teaching researcher or *JYY* is not a member of staff in any school. He or she works with a unit (i.e., the division of teaching research, or *Jiaoyanshi*) embedded in the administrative body of education at the various levels of the county, municipality, or province. For example, in Beijing, there are more than 120 teaching researchers of physics, chemistry, and biology at secondary school level, who are working with the district educational bureaus or with Beijing Municipal Educational Commission. These teaching researchers or *JYYs* used to be excellent school teachers, and now they are responsible for the professional development for science teachers (Hewson 2007) in the field of their own school subjects.

As teacher educators of school science teachers, teaching researchers or *JYYs* are different from science teacher educators in colleges and universities in that the former (JYYs) are practitioners with both rich experience and theoretical knowledge of pedagogical studies and they focus on practitioner research into science teaching, curriculum, evaluation, and professional growth and development for science teachers. On the other hand, the latter are academics much more interested in educational theory and research than the former. Specifically, the roles and/or responsibilities of teaching researchers or JYYs of science in mainland China include the following aspects:

1. **Research**. Teaching researchers or *JYYs* of science conduct research into curriculum, teaching, assessment, and professional growth and development for science teachers in ways that concentrate on the practical issues and problems in the above areas in their school subjects. For *JYYs* of science, the practitioner research they conduct is often done *with*, rather than *on*, school science teachers, and findings resulting from such research feed back to the *guidance* and *service* they offer to science teachers in order to improve science teaching and learning and to provide quality assurance of schooling in science.
2. **Guidance**. *JYYs* of science provide professional *guidance* for science teachers under his or her jurisdiction. Guidance rendered by *JYYs* concentrates on two cohorts of teachers: novice and leading teachers, for the reasons that the novice teacher will soon act as a qualified teacher, while the leading teacher will share his or her successful strategies or experiences with other teachers. For example, a *JYY* of physics at the Beijing municipal level may call a daylong professional meeting, whereby about 40 teaching researchers of physics and some of the leading physics teachers from the various districts and counties of Beijing (there are 14 districts and two counties within the city of Beijing) come together for learning about and discussing how inquiry-based physics teaching and learning is conducted in the classroom. These kinds of learning activities are often connected with the current curriculum reform policies, which school science teachers are required to implement and enact through the mediation of *JYYs* of science.
3. **Service**. It is also incumbent on *JYYs* of science to offer *service* to individual science teachers or a particular group of teachers to improve teaching quality by sitting in on and observing science lessons. For instance, if an experienced teacher of chemistry is asked by his or her school head to conduct an open

lesson (*Gongkai Ke*) for his or her colleagues to observe from the school or even from many schools in the district so that other teachers may learn from it, the *JYY* of chemistry in question is surely invited to give advice as regards how to best use the situation. Service afforded by *JYYs* of science also comes in the form of providing testing papers in school science subjects, for example, in the midterm or final examination each school year at county or district level.

Thirdly, the National Teacher Training Project (*Guopei Jihua*) has been initiated jointly by the Ministry of Education and the Ministry of Finance of China since 2010, whereby hundreds of thousands of practicing science teachers (and other subject teachers) have been selected to train in order to enhance the overall quality and professionalism. The National Teacher Training Project consists of two parts: the Project of Exemplary Teacher Training and the Project of Rural Key Teacher Training in central and western China. The provisions of the training are mainly located in normal colleges and universities, but sometimes also in leading high schools, with teacher trainers including university teacher educators, outstanding *JYYs*, and leading school principals and teachers of various subjects.

Problems and/or Challenges

In writing this entry, several pressing problems and/or challenges in respect of science teacher education in mainland China have come to mind. First, although science teacher education as indicated above has formed a unique Chinese model of (science) teacher education (Li 2012), can we say that this model is able to meet the needs of preparing high-quality teachers of science for mainland China? Second, inquiry-based science teaching and learning is singled out as one of the most important objectives of school science education both in mainland China and internationally. This is obviously a big challenge for both Western countries and China as well. Can the current Chinese science teacher education reform meet the challenge? Third, Chinese science teacher education research has adopted the tradition of German Didaktik (Fischler 2011), and meanwhile it has also accepted the Anglo-American tradition of science education research. In recent years, Chinese subject didacticians as science teacher education researchers have tried to integrate both the traditions in order to form a hybrid "curriculum and didactics of science" for various school subjects of science. Obviously, this seems to be another rigorous challenge for Chinese science teacher educators. To what degree can they succeed in making the integration? There are, of course, many other serious problems and challenges facing Chinese science teacher educators, but these problems and challenges stand out more manifestly and awaiting being addressed more urgently.

Concluding Remarks

Counting *Nanyang Gongxue* as the very first normal school that offered science teacher education in 1897, Chinese science teacher education has since undergone 116 years of development so far. The past century has witnessed a succession of identifiably historical pathways of science teacher education, each of which was appreciably marked by learning from other countries, sticking to China's cultural tradition, and adapting to social needs and changes influenced by a complexity of contemporarily political, economic, and educational factors. By integrating various elements from Japanese, Continental European, Russian, and Anglo-American models of science teacher education, there seems to have formed a *sui generis* Chinese model of science teacher education, based on Confucian epistemology that emphasizes the conception of "Chinese harmonism," expressed in the Confucian idea of "seeking for harmony but not the sameness" (*he er butong*) (Wang 2013). "With its core features of independence, openness, adaptability, and diversity based on Confucian pragmatism and epistemology," the Chinese model of science teacher education, despite its problems and challenges, "can provide alternative ways of thinking about the reform and change" (Li 2012) of science teacher education in the globalized world and, hopefully, will contribute to world science teacher education in the future.

Cross-References

- ► Didaktik
- ► Pedagogy of Teacher Education
- ► Science Education in Mainland China

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Science Teachers' Professional Knowledge

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Keywords

Science teachers' professional knowledge; Subject-specific knowledge; Teacher knowledge

Introduction

Science teachers' professional knowledge, or science teachers' knowledge, is a specific category of "teacher knowledge." Understanding the nature of teacher knowledge (science teacher knowledge in particular) and how it develops is important not only in (science) education research but also in (science) teacher education processes and practices.

Conceptualization of Teacher Knowledge

The meaning of "teacher knowledge" as a construct has evolved over time as it has been interpreted and cast in differing ways from diverse perspectives by different scholars. The main tension that underlies the understanding of the nature of teacher knowledge can be traced back to the dichotomy between theory and practice. With an interest in the epistemological aspects of research programs on teacher knowledge, Fenstermacher (1994, p. 3) made a distinction between "the knowledge that teachers generate as a result of their experience as teachers" and "the knowledge of teaching that is generated by those who specialize in research on teaching." He designated the former as "teacher knowledge: practical" and the latter, "teacher knowledge: formal." He argued that both theoretical and practical knowledge can enjoy legitimate epistemological status in knowledge claims as long as the demands for justification are meet.

Most research programs in the 1960s and 1970s were concerned with formal knowledge and involved understanding teacher knowledge from a theoretical or propositional stance. In these research programs, teachers were the objects of research, the "known" in Fenstermacher's term, and the researchers often saw themselves as producer of knowledge about effective teaching. The 1980s saw the rise of several new research programs with a particular interest in teachers' action in practice and the beginning of the shift in focus from propositional to practical knowledge. In these research programs, teachers were seen as the "knower" and the coresearcher or coproducer of knowledge about teaching (e.g., teacher as researcher). Researchers adopted various terms to refer to teacher knowledge, each emphasizing a particular characteristic of teacher knowledge. These terms included "personal practical knowledge," "professional craft knowledge," "practitioner knowledge," "knowledge in action," and "local knowledge."

It would be more productive to see Fenstermacher's distinction as a heuristic device in analyzing teacher knowledge claimed in various research programs rather than as exclusive categories that reinforce the dichotomy of theory and practice. Teacher knowledge is a complex construct in which knowledge and beliefs, conceptions, and intuitions are intertwined. Practical knowledge (such as routines and procedures) and propositional knowledge (such as theories, concepts, and principles) are often interrelated in teaching practice. A comprehensive review of perspectives on teacher knowledge and how it develops is offered by Munby et al. (2001).

Subject-Specific Knowledge and Science Teachers' Professional Knowledge

In an attempt to answer the question "what knowledge is essential for teaching?" Shulman and his colleagues based their research program on studying specialized knowledge for teaching in different subject areas. Shulman (1987) proposed seven categories of teacher knowledge: (a) content knowledge; (b) general pedagogical knowledge; (c) curriculum knowledge; (d) pedagogical content knowledge (PCK); (e) knowledge of learners and their characteristics; (f) knowledge of educational context; and (g) knowledge of educational ends, purposes, and values and their philosophical and historical grounds. Shulman's model made an important contribution to the research on teachers' subject-specific knowledge and has promoted the idea of a distinctive knowledge base for teaching as a profession.

Building on Shulman's theoretical framework and other researchers' work in the field, Abell (2007) proposed a modified model for mapping research on science teacher knowledge. This model highlighted the relationship between general pedagogical knowledge (instructional principles, classroom management, learners and learning, and educational aims), knowledge of context (students, school, community, and, districts), science subject matter knowledge, and pedagogical content knowledge for science teaching. She described science subject matter knowledge as including syntactic knowledge (knowledge of scientific inquiry skills and investigations) and substantive knowledge (knowledge in chemistry, physics, biology, and earth and space science). Pedagogical content knowledge for science teaching includes orientations toward teaching science, knowledge of science learners, knowledge of science curriculum, knowledge of science instructional strategies, and knowledge of science assessment.

Pedagogical content knowledge (PCK) is conceived as a specific form of teacher knowledge. Researchers who ground their work on pedagogical content knowledge find it a unique concept in promoting the professionalization of teaching. It is different from content knowledge in that it emphasizes the particular context of teaching and the interaction between teacher and student. It is also different from general pedagogical knowledge, because it is closely related to teaching particular subject matter. However, there has been more controversy regarding the connotations of pedagogical content knowledge than the definitions of science subject matter knowledge. Researchers have different views on the composition of pedagogical content knowledge, and they interpret the elements of this concept in different ways.

Implications for Science Education Research and Science Teacher Education

Research programs on science teacher knowledge have included both practical and propositional knowledge within the knowledge base for teaching. Teacher knowledge is a multidimensional concept. As a result, research programs adopt multiple instruments and methods. In some areas, such as science teacher subject matter knowledge, researchers share more common language in elaborating terminologies, describing theoretical frameworks, and comparing findings. In areas like pedagogical content knowledge, where researchers still do not agree about terminologies and methodologies, research programs are less cohesive, and researchers continue to seek common ground and to develop a research agenda both conceptually and methodologically. Despite these differences, researchers share the ultimate goal of improving student learning by improving teaching practice. It is hoped that understanding different aspects of teacher knowledge and their relationships will contribute to substantial improvement of teaching practice.

How the understanding of teacher knowledge (science teacher knowledge in particular) informs teacher education programs and policies is an important question. Teachers develop their knowledge from diverse sources, including daily practice and experiences, formal teacher education courses, and professional development. Recognizing that knowledge gained from all these sources can be integrated by teachers to form a conceptualization that might guide their teaching practice, teacher education program design and policy making have experienced a transition from emphasizing subject matter knowledge understanding through the specialist nature of pedagogical content knowledge. At the heart of science teacher education and development is the need to pay careful attention to not only what professional knowledge is but also how it develops and changes over time.

Cross-Reference

- ► Pedagogical Content Knowledge in Teacher Education
- ► Teacher Professional Development

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Science Teaching and Learning Project (STaL)

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Keywords

Case writing; Critical reflection; Professional learning; Professional practice; Reflective practice; Teacher thinking; Teachers as researchers

Science Teaching and Learning Program

The Science Teaching and Learning (STaL) program is the result of a collaborative project between the Catholic Education Office Melbourne, Australia, and the Faculty of Education, Monash University. The program aims to provide professional learning that supports the development of science teachers' practice (across years K-12), both individually and collectively (Berry et al. 2009). The program challenges teachers' existing understandings about conditions which enhance quality science learning and supports teachers to critically reflect upon, research, and report their understandings of their teaching and develop new knowledge of practice (Loughran 2006). To achieve this, teachers are provided with time to trial new ideas, information to consider alternative practice, and opportunities to both discuss their learning and recognize the emergence of new professional insights. The culmination of this knowledge resides in participants constructing and sharing "cases" of reflective practice drawn from their resultant classroom experiences.

Underpinning Program Principles

A number of assumptions about teacher professional learning underpin the STaL program and therefore shape the program's structural design and approaches to teacher learning. The first assumption is that change in practice occurs most effectively when it is self-directed and focused on individual needs and concerns. Therefore, placing the ownership of the learning directly in the hands of the teachers themselves is a guiding principle which underpins facilitator behavior in the program. Secondly, teaching is seen as problematic. Through the STaL program, science teaching is presented as dilemma-based requiring teachers to continually make judgments about what are appropriate actions in a given situation at a given time. Following from this is the assumption that there is not just one way of doing teaching (Loughran 2010). Each participating teacher is expected to hold some commitment to change and bring their expert judgment to bear on how change might be implemented in their practice.

Working from these assumptions the program seeks to empower participating teachers to identify alternative approaches in science teaching and recognize the impact of these approaches on student learning. It seeks to assist teachers to articulate explicitly what they value in their science teaching and encourage them to observe or notice any tensions which exist between what they say they value and what they actually do in their practice (Smith 2010). The program also seeks to support teachers to consider and create new conditions for learning in their own classrooms which realign professional thinking about quality science teaching with practice.

Conditions are established within the program to specifically attend to the learning needs of teacher participants. These conditions include realistic time for learning, interactive workshops, school-based support, and specific program time devoted to case writing. The program is spread across the school year as a 5-day program and takes place in two blocks of two consecutive days and a final day devoted solely to teacher case writing. Teachers are accommodated overnight for each 2-day program, demonstrating an explicit valuing of teachers as professionals and providing extended opportunities, both formal and informal, for teachers and facilitators to work and talk together. Sessions which explore a variety of aspects of science teaching and learning are conducted throughout the program, and teachers are encouraged to discuss and explore ideas in relation to their own teaching context and across the different contexts of primary and secondary schooling. A minimum of two teachers from each school are expected to attend the program, to assist with embedding teacher learning within a school context once the program itself has concluded.

School-Based Aspects of the Program

School-based meetings with program facilitators are conducted regularly throughout the program and are a valued and integral part of the program's design and philosophy. These school-based meetings provide an opportunity for participating teachers to reflect on areas of their science teaching so that they can identify the aspects of their practice which they want to understand more about and enable them to collect data from their classrooms related to their specific science teaching concerns. The discussions which occur in these meetings potentially stimulate rich insights for each teacher into their teaching and their students' learning of science (Berry et al. 2009). These discussions assist teachers to identify the aspects of their practice which they would like to share and to clarify their ideas in preparation for case writing.

Case Writing

The use of cases within the STaL project assists teachers to sharpen the focus of their practice on the learning of students and in turn enables them to see their own teaching through different eyes. The cases, which are published in a book form, help teachers to articulate what were previously implicit beliefs or feelings about practice (Lindsay 2012). The cases then provide a vehicle for sharing teacher knowledge from which other teachers can learn.

Case writing has a significant impact on participants as having their work published affirms them as professionals and affirms the specialist knowledge that they hold as teachers.

Cross-References

- ▶ In-Service Teacher Education
- ▶ Teacher Professional Development
- ▶ Teacher Research

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Science Theater/Drama

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Keywords

Theater

Drama/Theater in Science Education

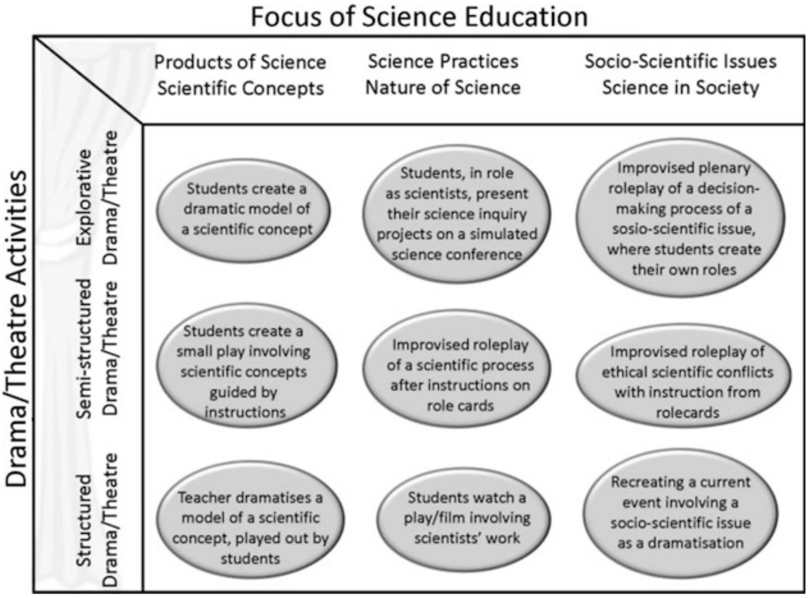
The liberal arts and science have traditionally been seen as two very different subject areas, indeed different cultures, and education seems to maintain this divide. However, they have much in common. Imagination and creativity play a critical role both in learning an art form such as drama and in learning science. Thus, these two disciplines can mutually help and inspire each other.

"Theater" and "theory" have a common etymological root in the ancient Greek verb "theorem," which means to see, to view, or to behold. The theoria in ancient Greece viewed the dramas of everyday situations and extracted truth. This kind of knowing, attempting to draw universal generalizations based on specific observation, is also viewed as a key epistemological feature of scientific explanations. The use of drama in a well-considered manner, guided by reflective science teachers, may provide empowering learning environments for students.

Perspectives of Science Education

There are many different examples of how drama and theater activities can be used in science education (see Fig. 1). Most traditionally, students explore the academic side of science with its products, models and scientific concepts that explain natural phenomenon. Within the known framework of scientific theories, students may, for instance, play electrons in a circuit to illustrate and get a deeper understanding of the scientific concept of electricity. The process of transferring the model or description from the textbook to a three-dimensional live model requires the students to reconceptualize their knowledge. Through the process of social interaction that involves both verbal and physical activities, students increase their understanding. In addition, teachers have an expanded ability to assess students' understanding immediately under the course of the activity and give feedback to deepen the students' understanding.

Another important perspective of science education is scientific processes, which involve understanding science practices and nature of science. Scientific processes are centrally concerned with scientists' experimental and



Science Theater/Drama, Fig. 1 Overview of aspects of theater and drama activities in science education, inspired by Ødegaard (2001, 2003)

conceptual work, both in the laboratory and elsewhere. The students' only experience of this is often through predesigned laboratory exercises, which do not authentically reflect the scientific process. In particular, the important communication process between researchers, in which discussion and debate occurs, is seldom mentioned. Letting students take on the mantle of an expert and role-play scientists doing scientific inquiry reveals many aspects, both practical and social, of scientific practices to the students. Also, once given insight into a set of science stories, students will have the opportunity to understand that nature of science is not the same as predesigned laboratory exercises. Through stories of science and experiences in enacting scientists, students are offered more possibilities to gain insight into the reality of the process of scientific practice. Many students find drama methods lively and stimulating and thus more memorable. They give a sense of the richness and complexity of the events they relate to, beyond that of simple textbook or other written accounts.

In addition, classroom dramas and theater-related activities are beneficial for focusing on the science in society perspective and socio-scientific issues in science education. Just as a well-known method in science is to make a simulation in the laboratory of a phenomenon in nature, so it is possible to simulate societal processes that relate to science, for instance, an international environmental conference, a consensus conference, or other democratic processes. The real world is brought into the classroom in the context of practical action. Divergent interests and ethical conflicts are essential to decision-making processes, as is also shown in all good plays and dramas. In role-play, the conflicts, combined with the personal relations the students develop to the issue, make them able to act. Students explore situations that create empathy and identification; thus, thoughts, knowledge, and feelings are stimulated and give room for action. Science is recontextualized to a situation where it has human scope and force. The cross-curricular potential in drama gives the opportunity for a style of learning that does not break knowledge and skills into artificial units, but permits exploration of the world using whatever medium is appropriate.

Aspects of Theater and Drama Activities

Dramatic activity may vary and take many different forms in the classroom. The drama may be structured in a way where students enact pre-prepared roles within a known framework of, for instance, scientific theories (e.g., playing electrons), or the dramatic activity may be impulsive, creating the moment, as it were; students have to improvise who they are and what to say. At any point along this continuum, a drama can be more or less spontaneous. An intermediate form could be an improvised role-play with a structured frame (e.g., role cards that describe the participating roles).

Another continuous variable is the degree of teacher involvement, that is, whether it is the teacher that impels the drama or the students. A group of students who create their own model of a scientific concept are together reconstructing knowledge so as to enhance their conceptual understanding. In order to guide the students, it may sometimes be necessary for the teacher to provide scaffolds in complicated scientific matters.

Dramas may also be characterized according to whether they are presentational or experiential. Presentational dramas have a major emphasis on communicating something to others outside the drama (e.g., the teacher, peers, or parents). They can be seen as plays with many theatrical features. When a small group of students dramatize a scientific concept (e.g., make a "meiosis ballet"), the intention is often communication to others. Another option is that students watch a play performed by others who, for instance, want to communicate issues involving science or scientists' work. This may give students a common experience to reference when, in this case, trying to understand nature of science. The experiential dramas, however, have focus on attempting to *live through* some aspect of an experience and exploring an opinion or attitude (e.g., a role-play with role cards about ethical issues in biotechnology). However, the division is not clear. When students themselves make a presentational drama of a scientific issue, it can be seen as an inquiry process, where imagination and creativity play a crucial role in making representations of science concepts. Thus, through the presentational drama, students may experience insights that deepen their understanding of scientific issues, giving the drama experiential facets.

Cross-References

- ▶ Critical Issues-Based Exhibitions
- ▶ Role-Plays and Drama in Science Learning
- ▶ Science Museum Outreach

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Science Tourism

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Science tourism is travel outside one's usual environment to learn about or participate in science. It includes specific types of tourism that are motivated by an interest in science, visitation of attractions that present science, travel to sites or events of scientific significance, science volunteer tourism, and school science field trips.

Many different types of tourism are **motivated by an interest in science**. Nature-based tourism, which includes more specific subtypes such as ecotourism, geotourism, and wildlife tourism, relies on immersion in and interaction with nature. Nature-based tourism activities include hiking; bird watching; snorkeling; whale watching; stargazing; visiting geothermal sites, alpine areas, deserts, and rainforests; and a multitude of other activities, all of which provide important opportunities for science learning. Such experiences are often enhanced by the provision of environmental interpretation, which aims to communicate scientific concepts while also creating opportunities for visitors to understand, appreciate, and enjoy the natural environment. Interpretation might be delivered by signs, brochures, displays, park rangers, or tour guides and is specifically focused on the natural features or species that visitors can experience firsthand at the site visited. Nature-based tourism has an added advantage in that it provides a financial incentive for the conservation and sustainable management of natural resources. Other types of special interest tourism with a science focus are also emerging. For example, space tourism offers opportunities for recreational space travel that may involve not only learning science but also participating in research activities while in orbit. Another emerging form of tourism known as “last chance tourism” involves traveling to places that are threatened by environmental factors such as climate change or overpopulation, in order to experience and learn about these places before it is “too late.”

Tourist attractions that specifically present scientific information include zoos, aquaria, botanic gardens, planetariums, national parks, science centers, natural history museums, and space museums. Social history museums and art museums may also host special exhibitions that present science either as their main purpose or incidentally, e.g., the popular *Body Worlds* exhibitions, *Leonardo da Vinci* exhibitions, and *Titanic* exhibitions. Visits to historical sites provide opportunities for learning about archaeology, architecture, or the science of conserving or restoring artifacts. Scientific information is often presented and interpreted at sites of important engineering feats, such as bridges, tunnels, and dams. Even a visit to a theme park can be enhanced by a presentation of the principles of physics that underpin the operation of amusement rides.

Tourists increasingly search for unusual and unique experiences. These may include **travel to sites of scientific significance, travel to witness science phenomena, or travel to attend science events**. Examples of significant sites are the Galapagos Islands, where visitors can follow in the footsteps of Charles Darwin; the Kennedy Space Center, where visitors can take a tour of NASA’s launch sites and even view a launch; and the European Organization for Nuclear Research (CERN), where visitors can learn about the fundamental research done at the world’s largest particle physics laboratory. Tourists also seek out the former homes of, burial sites of, or memorials dedicated to famous scientists, such as Isaac Newton, Marie Curie, Nikola Tesla, Albert Einstein, and Alan Turing. Science tourists may visit astronomical events such as eclipses, transits, or aurora that can only be viewed from particular locations; biological events such as coral spawning; or unique geological or geothermal phenomena such as unusual rock formations, glaciers, volcanoes, or geysers. Science events such as science festivals, conferences, and climate summits attract both scientists and hobbyists from around the world.

Science tourists can **volunteer to join a research expedition**, such as those organized by the Earthwatch Institute, where they can work on projects in wildlife conservation, rainforest ecology, marine science, and archaeology. This provides both a source of funding and practical assistance to scientists in collecting field data.

Finally, when school groups take **field trips** for the purpose of learning science, they also are participating in science tourism. Engaging in hands-on learning in real-life contexts enhances student motivation and increases the likelihood that science learning will be transferred to situations that students encounter outside of the school environment.

Increasingly, tourists seek travel experiences that engage them intellectually and develop their breadth and depth of general knowledge and understanding of the world. Travel offers many such opportunities for experiential learning in unique and unusual contexts which are likely to be both memorable and deeply rewarding for participants. Science tourism is thus an effective and increasingly important contributor to the lifelong learning of science in out-of-school contexts.

Cross-References

- ▶ Interpretive Centers
- ▶ Learning Science in Informal Contexts
- ▶ Out-of-school Science

Science, Technology and Society (STS)

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Keywords

Context

Introduction

Over the years, a range of factors including increased attention towards science and social responsibility, the prevalence of socio-scientific issues such as genetic engineering and nuclear power, a desire to humanize science, decreasing enrolment in physical sciences, and a surge of interest in the environment, have provided a fertile ground from which Science Technology Society and Environment (STSE) education has emerged. Originally, this movement began as Science Technology and Society (STS) education and then later evolved to include the environment (STSE). In this entry, we use STSE throughout, understanding that its roots are STS.

At a macro level, STSE education examines the interface between science and the social world. It is an umbrella term that supports a vast array of different types of theorizing about the connections between science, technology, society, and environment, and places science squarely within social, technological, cultural, ethical, and political contexts. At a micro level, STSE education includes decision-making, the coupling of science and values, integration (with other subject areas), nature of science (NOS) perspectives, and action. For many, STSE represents a shift from the status quo, a post-positivist vision for science education that emphasizes a *science for all* philosophy. What is clear is that there is no single, widely accepted view of STSE education. STSE in theory and practice emerges from different places for different people, influenced by particular contexts and circumstances and used for different purposes.

One of the earliest mentions of STSE appears in an article written by Jim Gallagher (1971) in *Science Education*. He argued strongly for a broader model of science teaching that included understanding the conceptual and process dimensions of science, as well their relationships to technology and society. Joan Solomon's and Glen Aikenhead's work (see, e.g., Solomon and Aikenhead 1994) did much to bring STSE to the fore. A range of significant texts during the 1980s and 1990s marked an ongoing commitment to STSE education and a collective desire for fundamental change in school science. Today, this desire for change in school science continues. For many jurisdictions STSE has become an important part of school science curriculum and the student experience.

Structure of the Field (STSE Theoretical Frameworks)

From what has gone before, it is clear that STSE is a complex construct. Other than a few broad principles, it is difficult to define what exactly constitutes STSE education. Indeed widely differing discourses have led to an array of distinct approaches, programs, and methods. To a great extent this is simultaneously the strength and weakness of the STSE movement. Despite this fluidity, over the years several have tried to develop classifications or typologies to pinpoint a structure for STSE and guide its further development, particularly its implementation in classrooms. However, it is important to note that these various schemas are not easily comparable. In particular no one is more comprehensive or more correct than the others. Rather the various efforts provide insight into different dimensions of the topic.

Ziman (1994), one of the earliest advocates of STSE, provides a general conceptual framework, useful for locating STSE and supportive of a multiplicity of approaches for its implementation. According to Ziman (1994), STSE contains philosophical, sociological, and historical dimensions, which in themselves can serve as approaches for implementation. Additionally, he proposes that STSE contains other ideological dimensions suggestive of other approaches, for example, utilitarian (vocational, relevance), transdisciplinary, and problem-based approaches. While Ziman's work is mostly philosophical and theoretical in nature, Aikenhead (1994), on the other hand, has written extensively about the spectrum of meanings and degrees of STSE inclusion found in existing science courses and programs. He captures the relative importance afforded to STSE by analyzing content structures and methods of student evaluation within a wide variety of science courses. Aikenhead's classification consists of eight categories that represent a spectrum. At one end (category one), STSE content is given the lowest priority compared to traditional science content, while at the other end (category eight), it is given highest priority. The eight categories are as follows: (1) motivation by STSE content, (2) casual infusion of STSE content, (3) purposeful infusion of STSE content, (4) singular discipline through STSE content, (5) science through STSE content, (6) science along with STSE content, (7) infusion of science into STSE content, and (8) STSE content. It is important to note that this scheme does not attempt to link STSE to any particular set of educational goals or priorities nor does it address specific teaching methods. In other words, Aikenhead's work describes *how* STSE might be integrated into the science curricula, but not the *why* and *what* of STSE education.

Pedretti and Nazir (2011) provide a classification that tackles these latter aspects. They provide a typology of possibilities for STSE education or what they call "currents" through consideration of the overall aims of science education, perspectives from the psychology of education, and examples of strategies or pedagogy for science programs. Within their typology, they identify and explore six currents in STSE education: (1) application/design, (2) historical, (3) logical reasoning, (4) value centered, (5) sociocultural, and (6) socio-ecojustice. They characterize the sociocultural current, for example, as promoting an understanding of science and technology within a broader sociocultural context, while engaging in an analyses of the complex social structures within which science operates. They link this current to the overall aim of teaching science as an important cultural and intellectual achievement and identify its dominant approaches as holistic, reflexive, experiential, and affective. Examples of pedagogical strategies include the use of case studies, storytelling, and integrated curricula. While Pedretti and Nazir are careful to caution that their classification is not exhaustive and that no current is "better" than the other, they suggest that their typology can be used by educators for critical analysis of the various discourses and practices within STSE, as it exists today.

Challenges to STSE Education

STSE programs and themes have been developed worldwide, at the elementary, secondary, and tertiary levels. In general, programs have been designed in an effort to interpret science and technology as complex socially embedded enterprises and to promote the development of a critical, scientifically and technologically literate, citizenry capable of understanding STSE issues, empowered to make informed and responsible decisions, and able to act upon those decisions. In Canada, for example, several provinces have continued to emphasize STSE as an important part of school science and retain it as an integral and primary focus of K-12 science curricula.

Although (STSE) education has gained considerable force in the past few years, it has made fewer strides in practice. An emphasis on STSE education presents challenges for educators – both practical and ideological in nature. Many have written about the practical challenges inherent to adopting an STSE approach. Practical challenges and barriers include the following: lack of time and resources, assessment issues, lack of professional development opportunities in STSE, and issues related to teacher confidence. Many fear that extensive coverage of socio-scientific subject matter devalues the curriculum and may alienate some science students. Furthermore, STSE instructional strategies often include, for example, town halls, debates, and role-plays. These activities (with their focus on decision-making, ethics, action, transformation, and empowerment) are not traditionally part of science teachers' repertoires.

Fewer, however, have written about the ideological bents and assumptions that underpin different formulations of science education in general and STSE education in particular. For example, a view that science education should be focused on teaching science content (a predominantly transmissive view) rather than focused on social reconstruction and change (a transformative view) can produce radically different experiences and challenges in the science classroom. For example, coupling science and values education can be problematic for some. How do educators reconcile teaching about science and values? How does a teacher position himself/herself? How do teachers address personal values in the classroom and accommodate diverse views, cultural contexts, and ways of thinking about the world? Action and the politicization of science present another set of problems. The notion of a sociopolitical science curriculum that promotes social justice and transformation provides a very different vision of science teaching and science education, and for some, this can be disconcerting. Such competing ideologies represent a major shift in the way that science education and therefore science teaching are conceptualized and may challenge science teachers' professional identities. These practical and ideological challenges provide rich avenues for future research in STSE education that is rooted in classroom praxis, pedagogy, teacher professional development, and student learning.

STSE and Other Related Movements

STSE has evolved to include other movements and manifestations. In Pedretti and Nazir's (2011) mapping of the field, they use the metaphor of currents to describe the evolution of STSE over time. According to them, STSE education is comparable to a vast ocean of ideas, principles, and practices that overlap and intermingle one into the other. At any one time the field has been characterized by certain ideas coming together to form discernible currents. These currents are constantly changing and shifting according to the context in which they occur. It can be argued that new and emerging currents remain within the STSE fold because they share a similar post-positivist view of science and science education discussed earlier on.

Two currents or movements that have evolved over time and which are particularly strong today are socio-scientific issues (SSI), based on the work of Dana Zeidler and his colleagues, and environmental education (EE). It can be argued that SSI and EE share similar principles, visions, and pedagogies as STSE education (although proponents of these movements may argue differently). The SSI movement pays particular attention to the ethical aspects contained within socio-scientific issues. It focuses on the moral and character development of students. Zeidler's work takes a justice-based, cognitive moral developmental approach to science education. He proposes the use of carefully selected problems from the domain of science to stimulate moral deliberation and consequently moral development in science classes. The SSI model is fortuitously supported today by a resurgence of interest in values education worldwide. Environmental education is another strong current within STSE today. EE, in general, has been gaining momentum worldwide, as the idea of humankind's negative impact on the environment and the consequences for the continued existence of all life on the planet becomes increasingly accepted. STSE has always shared many of the philosophical and educational ideas underpinning the ecojustice movement. In particular, EE derived from an STSE base tends to emphasize the economic and sociopolitical aspects of environmental problems and the need to provide people with the tools (skills, knowledge, and dispositions) to actively transform society. Citizenship that promotes civic responsibility (to humans and non-humans), agency, and emancipation are key features of this current.

In conclusion, STSE education situates science in a rich and complex tapestry – drawing from politics, history, ethics, and philosophy. Although a challenge politically, ideologically, and practically, STSE presents an opportunity to learn, view, and analyze science in a broader context while recognizing the diversity of needs of students and classrooms. STSE, in its many forms and currents, brings relevancy, interest, and real-world connections to the science classroom.

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► Socioscientific Issues

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Science, Technology, and Engineering Interrelationships: Assessment of the Understanding of

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Keywords

Assessment; Engineering; Interrelationships; Science; Technology

In most reports setting forth frameworks or standards for science, technology, and engineering, the three domains are described as related by their focus on systems in the real world yet different in the roles that the disciplines play in understanding and modifying the world. The definitions for this entry are based on documents produced by national sets of experts in which the relationships of science, technology, and engineering are described. Definitions of science, engineering, and technology can be culled from these frameworks and standards developed by engineering and science organizations, as well as from standards for engineering and technology for state, national, and international assessments.

These definitions of science, technology, and engineering are the starting points for developing assessments of understanding of the ways in which they are related. This entry begins with a summary of prominent conceptualizations of science, technology, and engineering. The definitions are followed by descriptions of an assessment framework that can be used to select or develop and assessments of understanding the similarities and differences of science, technology, and engineering. Descriptions of some potential types of assessment tasks and items to test understanding of the interrelationships of science, technology, and engineering are provided.

Definitions of Science, Engineering, and Technology

Science refers to understanding and studying phenomena in the natural world, while engineering and technology are applications of science to create the human-made world. Engineering is defined as a systematic and iterative approach to designing objects, processes, and systems to meet human needs and wants. Technology is defined as any modification of the natural or designed world developed to fulfill human needs or desires. Technologies, therefore, are products and processes resulting from application of engineering design processes. Technologies also often function as tools and processes used to support engineering design.

Sources of Conceptualizations of Science, Technology, and Engineering

Framework for K-12 Science Education and the Draft Next Generation Science Standards

The framework provides a broad description of the content and sequence of learning in science and engineering expected of all students by the end of high school. Science disciplinary core ideas, crosscutting concepts important in all disciplines, and practices describing the ways scientists and engineers work are presented. Engineering and technology are included as applications of science. Core ideas are specified for physical, life, and earth and space sciences and for engineering and technology. These key disciplinary areas are integrated with foundational crosscutting concepts such as cause and effect, systems and models, and patterns. The science and engineering practices include skills for asking questions and defining problems, developing and using models, planning and carrying out scientific investigations, analyzing and interpreting data, and using mathematics and computational thinking.

Engineering is used to mean engagement in a systematic design practice to achieve solutions to particular human problems. Technology is used to include all types of human-made systems and processes. Two core engineering ideas are specified. The first is engineering design – how engineers solve problems. The second core idea is understanding of the links among engineering, technology, science, and society. Engineering design is subdivided into three components: (1) defining and delimiting a problem, (2) developing possible solutions, and (3) optimizing the design solution. Links among engineering, technology, science, and society are partitioned into (1) interdependence of science, engineering, and technology and (2) the influence of engineering, technology, and science on society and the natural world. The framework describes grade band end points for each of the three components.

The draft Next Generation Science Standards provides more specific guidance for assessing scientific ideas and engineering design that produces and uses technology. For example, performance expectations have been developed that integrate the engineering core ideas with crosscutting concepts, such as systems and models and cause and effect, and also with science and engineer practices.

Technology and Engineering Literacy (TEL) Framework for the 2014 National Assessment of Educational Progress

TEL framework is unique in its focus on assessing the interrelationships of engineering and technology. In the framework, technology and engineering literacy is defined as the capacity to understand technology and engineering design principles and to use and evaluate engineering design processes (NAGB 2010). Technology and engineering literacy is divided into three assessment areas, design and systems, information and communication technology, and technology and society. Within design and systems, three subareas of essential knowledge and skills were identified: nature of technology, engineering design, system thinking, and maintenance and troubleshooting.

Principles for the nature of technology expand the scope of common conceptualizations of technology beyond computers and the Internet. The broader view includes every way people manipulate the natural environment to satisfy needs and wants. Therefore, technology includes all the various devices and systems that people make to fulfill some function. The framework lays out key principles for the nature of technology: (1) technology is constrained by the laws of nature; (2) scientists examine what exists in nature, and engineers modify natural materials to meet human needs and wants; (3) technological development involves creative thinking; (4) technologies developed for one purpose may be adapted for other purposes; (5) science, technology, engineering, and mathematics and other disciplines are naturally supportive; (6) the pace of technological change has been increasing; and (7) tools help people to do things efficiently, accurately, and safely. The framework then lays out assessment targets for grades 4, 8, and 12.

The engineering design subarea in the TEL framework is described as an iterative, systematic process for solving problems. The process begins with stating a need or want and the criteria and constraints of the challenge. Then potential solutions are explored referencing relevant scientific and technical information. Potential solutions are compared, and models and prototypes are constructed, tested, and evaluated to see how they meet the criteria and constraints of the problem. The results of the engineering design process will be technology in the form of either a product or a process. The framework specifies key principles of engineering design and proposes assessment targets for grades 4, 8, and 12. Two additional components of design and systems are systems thinking and maintenance and troubleshooting. For each component, principles are identified and assessment targets for grades 4, 8, and 12 are presented.

The framework also specifies components, principles, and assessment targets for grades 4, 8, and 12 for the prominent technology area of information and communication technology (ICT). ICT is presented as a separate assessment area within technology and engineering literacy because of the central place ICT plays in learning and functioning in school, the workplace, and daily living. ICT subareas to assess include understanding and use of technologies for (1) construction and exchange of ideas and solutions, (2) information research, (3) investigation of problems, (4) acknowledgment of ideas and information, and (5) selection and use of digital tools.

Each of the frameworks and standards described above can serve as resources for specifying the interrelationships of science, technology, and engineering to be assessed.

Evidence-Centered Assessment Design

The focus of this entry is on methods for assessing understanding of the interrelationships among science, technology, and engineering. The selection or development of assessments will depend on the purposes of the assessments and the interpretations of the data. An assessment may be intended to provide diagnostic feedback and be used in a formative way to allow adjustments during instruction to improve performance. An assessment may be intended to serve a summative purpose to report on the status of proficiency at a point in time. These purposes will have implications for the criteria used to select, design, or interpret assessments.

A useful framework for understanding the structure of assessments is evidence-centered assessment design (Mislevy et al. 2004). Evidence-centered design is intended to structure an assessment argument. The argument begins with the claim that specified knowledge or skills have been learned. Evidence to support the claim comes from the types of questions or tasks that will elicit observations and performances of the targeted knowledge or skill. Summaries of performances, typically in the form of scores to be reported and interpreted, then complete the argument. Evidence-centered assessment design tightly links the targeted knowledge and skills (student model), with assessment tasks and items to elicit evidence of these targets (task models), with specifications of how the evidence will be scored and analyzed to report proficiencies (evidence model). The evidence-centered design framework can be used to analyze and evaluate existing assessments or to guide the systematic development of new ones.

The essential first step in assessing student understanding of the interrelationships of science, technology, and engineering will be to settle on the definitions of science, technology, and engineering and to specify the similarities, differences, and roles to be tested. The features and functions would become the first component of the student model. A second component of the student model would be the cognitive demands or levels of reasoning required. Cognitive demands could range from identifying definitions and lists of similar and different features to analyzing the roles of science, technology, and engineering in scenarios; to actually applying ideas and practices in relevant problems involving the use of science, engineering, and technology; and to evaluating others' applications of science, technology, and engineering in a range of scenarios.

The engineering design process creates plans for developing solutions. Solutions may be tangible artifacts or technologies, such as digital devices or farm machinery. Solutions may rely on scientific knowledge and new or improved technological processes such as more efficient manufacturing procedures or pharmaceutical clinical trials. These solutions are technologies that have been developed to address needs in areas of the designed world such as medicine, agriculture, energy, transportation, manufacturing, and construction. Students tend to think of technology in terms of computers and digital technologies, not in terms of the artifacts and solutions engineered in the many other areas of the designed world. Students are expected to understand that there are technologies in all these areas, from pills, plows, plugs, planes, and pinions to pickup trucks. Specifications of the knowledge to be tested will need to decide what students need to understand about the distinctions and overlaps among science, technology, and engineering. It is likely that such discriminations would be part of a more comprehensive assessment of scientific, engineering, and technology problems and contexts in which they occur. Therefore, statements of what the student needs to know and the level of reasoning for showing it will become the assessment targets of the student model.

In evidence-centered assessment design, the task model specifies the kinds of contexts, problems, and items that would elicit evidence that the students understood the relationships of science, technology, and engineering. Simple items could list features of scientific ideas and practices, engineering design processes, and technologies and have students select examples of their appropriate use to given problems. Descriptions of needs addressed by an engineering project that is producing solutions could include questions to determine that students understood about the role of scientific knowledge contributing to the solutions and whether new tools or new processes are technologies. Tasks and items could be designed around scenarios presenting scientific questions and engineering design problems in a range of applied contexts. An overarching problem could be to select scientific knowledge, technologies, and engineering processes to use in attempting to solve the problem or to critique descriptions of their appropriate use in scenarios.

The SimScientists program has developed simulations to assess understanding and use of science and engineering practices for a number of science systems (Quellmalz et al. 2012b; http://simscientists.org). As shown in Fig. 1, a scenario was developed in which students are working to establish a sustainable research center in Antarctica. By harnessing available sunlight and wind, scientists at the station are able to generate electricity, which can be used for the electrolysis of water, which in turn results in the production of hydrogen gas. The simulation-based assessments have been designed to assess core ideas about atoms and molecules, changes in state, properties of matter, and the science practices of designing and conducting investigations. The scenario could be augmented with sets of tasks about the design, testing, and troubleshooting for an energy production, conversion, and

The research center uses wind and sunshine to generate electricity. You can use the electricity to create hydrogen without producing any pollution!

Now that you have a way to generate hydrogen gas, your next task is to find out how to use hydrogen for cooking.

You need to know what conditions caused a reaction in the flask. You will need to answer the following questions about hydrogen gas.

Does hydrogen react with oxygen if there is a spark?
Does hydrogen react with oxygen whenever they are mixed?
Does hydrogen react with nitrogen if there is a spark?
Does hydrogen react with nitrogen whenever they are mixed?

Review your trials and decide if you have enough information to answer the questions to the left.

- If you want to review one of your trials, click the VIEW button for that trial.
- You can then click RESET to start that trial again.
- If you need to run another trial, click NEW TRIAL.
- When you are satisfied with your trials, click NEXT.

Science, Technology, and Engineering Interrelationships: Assessment of the Understanding of, Fig. 1 SimScientists simulation-based assessment

storage system that contributes to a sustainable research center.

As foundational computer models of such systems, natural and man-made, are developed, they can support the development of tasks to assess science, technology, and engineering concepts and practices and also to assess twenty-first-century skills such as communication and collaboration (Quellmalz et al. 2012a). For example, students could be asked to construct descriptions for the Antarctic Research Center Board for a proposed sustainable energy plan or to critique if solutions proposed by others meet the design constraints. A virtual collaborator could be queried to seek relevant information about the trade-offs of alternative sustainable energy treatments.

The assessment evidence model would involve determining what kind of scoring and reporting would convey that the student understands the similarities and differences and roles of the three areas. Specific reports about progress and proficiency on the assessment targets would be needed.

The assessment selection or development can use the framework of evidence-centered assessment design to guide analyses of existing tasks and items or to guide the development of appropriate tasks and items. The framework would ask if the knowledge to be tested is clearly specified (student model) and if the tasks and items will provide evidence if the knowledge and practices have been applied in a range of areas such agriculture, medicine, and manufacturing. The framework would also ask if the scoring and reporting clearly allowed decisions to be made about whether the understanding of the interrelationships of science, technology, and engineering is sufficiently strong. The decisions could then be used diagnostically to inform further instruction or to inform a proficiency report. The key to sound assessment is that the assessment argument is clear and supported.

Cross-References

- ▶ Assessment of Knowing Engineering and Technology and Doing Engineering and Technology: Overview
- ▶ Engineering Design, Assessing Practices of
- ▶ Technology, Assessing Understanding of

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Science, Technology, Engineering, and Maths (STEM)

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Keywords

Engineering; Technology

Historical Foundations

Historically, science had a place in education before the time of Plato and Aristotle (e.g., Stonehenge). Technology gradually increased since early human inventions (e.g., indigenous tools and weapons), rose up dramatically through the industrial revolution and escalated exponentially during the twentieth and twenty-first centuries, particularly with the advent of the Internet. Engineering accomplishments were evident in the constructs of early civil works, including roads and structural feats such as the Egyptian pyramids. Mathematics was not as clearly defined BC (Seeds 2010), but was utilized for more than two millennia (e.g., Archimedes, Kepler, and Newton) and paved its way into education as an essential scientific tool and a way of discovering new possibilities. Hence, combining science, technology, engineering, and mathematics (STEM) areas should not come as a surprise but rather as a unique way of packaging what has been around for centuries. For education, the acronym STEM has emerged to initiate innovations in curriculum design and practices mainly towards facilitating career choices in these much needed fields.

What Is STEM?

STEM education is an opportunity to develop competencies in high-demand fields. Engineering education has not been included traditionally in school education; however, its inclusion presents hands-on problem-based activities for fusing science, technology, and mathematics to engage students in engineering innovations. The scientific and mathematical undertakings towards devising technology with the assistance of Internet information and communication have facilitated engineering advancements across a range of fields (e.g., chemical, structural, mechanical, civil, software). The abundance of engineering positions and scope for increased developments has lead towards engineering education beginning earlier within school systems (e.g., primary and middle schools).

Various countries are positioned to promote STEM education. In 2008, the US government commissioned reports on how to transform STEM into implementable educational programs and, early in 2010, President Obama committed $3.7 billion for STEM education in his 2011 budget (National Institutes of Health 2010). Malaysia, as another example, up to 2012 had outlaid significant funds for up-skilling STEM teachers across their country, particularly with the uptake of degrees from outside providers, and the UK is establishing national STEM education networks (e.g., see http://www.dcsf.gov.uk/stem/). There are STEM education initiatives in Australia, for instance, the Department of Education, Science, and Training (DEST) supported financially 355 projects conducted between 2005 and 2007, out of which 83 projects combined the STEM areas (see http://www.asistm.edu.au/asistm/). Although these initiatives were largely isolated occurrences involving pockets of partnerships that did not appear to have significant impact on schools outside the original arrangements, they commenced a process towards forming a national STEM agenda.

STEM Education

In a resource-driven world, university enrolments in STEM areas have not met career demands, which is a rationale for profiling STEM education. Importantly to the STEM agenda is the focus on females, as they are largely underrepresented in STEM at the university level. For example, in 2012 there were only 11–15 % undergraduate enrolments in engineering across Australian universities with the 2009 Melbourne Declaration advocating a STEM education agenda by building the capacity of STEM teachers. Part of the reason for low female involvement in STEM fields lies in stereotyping female competencies; hence, there are calls for establishing a gender equity curriculum for STEM education to overturn stereotypical views, especially during the early years of education and into the STEM workforce. Furthermore, the underrepresentation of females in STEM areas has driven researchers to explore ways to uncover how to engage and motivate females into these fields. Websites have been launched to address the gender gap in STEM areas such as engineering (http://www.engineergirl.org/), which in particular aims at educating middle-school females. For both genders, educational advancements must include hands-on activities that aim to increase students' confidence and interests in STEM.

Ongoing STEM development

Further developments in STEM education are needed to initiate, promote, and sustain its theoretical structure in education, some of which can include establishing STEM education forums. For instance, the first international STEM in Education conference in 2010 (http://stem.ed.qut.edu.au/) provided a platform for educators to share knowledge in and across their respective disciplines. The conference moves around internationally (e.g., Beijing Normal University, 2012 and University of British Columbia, 2014) to engage educational communities in the STEM education fields. Indeed, other STEM conferences (e.g., www.genderandSTEM.com and the UK STEM Annual Conference) are sprouting up around the world to facilitate conversations on relevant STEM topics. STEM education holds promise for educating current youth into high-demand STEM careers emanating from a worldwide growth in developing and manipulating resources.

Cross-References

▶ Science, Technology and Society (STS)

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Scientific Language

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Keywords

Argumentation; Interpretive system; Language; Meaning-making; Metaphor; Science

There is nowadays extended consensus around the recognition that scientific knowledge is "dependent inextricably on language and language is also central to our ability to think [scientifically]" (Evagorou and Osborne 2010, p. 136). Language thus becomes a key element in science education: it is a tool that allows us to understand the natural world, to express our ideas on it, and to develop scientific knowledge. This paramount role of language in supporting science learning processes was acknowledged at least five decades ago, notably through the seminal work of Jerome Bruner; such acknowledgment can be attributed – at least partially – to the dissemination of Lev Vygotsky's ideas in English. However, it was not until the 1980s, and following developments in the philosophy of science and in educational studies, that science education research began to pay attention to the linguistic aspects inherent to science teaching. As a consequence of this new focus, in the last two decades, a thriving research line has emerged, with several theoretical perspectives that focus on different aspects of the issue of scientific language in the classroom (e.g., Sutton 1996; Lemke 1990; Sanmartí et al. 1999).

Sutton (1996), in his now classic paper *Beliefs about science and beliefs about language*, portrays two distinct epistemic functions of language in science: language can serve *as a labeling system*, to tag and transmit established pieces of knowledge, or *as an interpretive system*, actively used to generate and consolidate new understandings. In that text, Sutton is advocating for shifting from the positivistic emphasis on language as a means of conveying conceptual information toward the constructivist idea of understanding language as a way of meaning-making.

Adhering to such characterization of scientific language for the science classes would import the need to introduce students simultaneously in the patterns of reasoning and the patterns of language that are developed in the context of doing science. Along this line, Evagorou and Osborne (2010, p. 138) claim:

> [B]ecause reading and writing are activities that are constitutive of science, and because the language of science is complex and foreign to many students, we see teaching science as fundamentally a process of teaching a language – one in which the teacher has both to help students to interpret and construct meaning from scientific text and one in which they must provide opportunities to develop their fluency and capabilities with that language. In the classroom, three main forms of language are used as tools for understanding, communicating, and developing knowledge: talk, writing and reading.

In the same spirit of the previous paragraph, Lemke (2001) argues that we could understand science education as a "second socialization": an enculturation into a subcommunity – science – that has its own representations, methods, ethos, and jargons. This theoretical approach should motivate us to examine how people learn to talk and write the language of science while engaging in specific scientific activities, such as observing, experimenting, debating, or publishing. In his well-known book *Talking Science*, Lemke (1990) equates science learning, at least partially, to learning to "talk science." This implies moving away from science lessons dominated by a "triadic dialogue" centered on teachers' talk – as in the classical IRF (initiation-response-feedback) sequences. Here, Lemke introduces a very suggestive idea: talking science could be considered a very elaborate social process, modeled on the metaphor that science is a foreign language that students have to learn.

In his own words:

> Learning science means learning to *talk* science. It also means learning to use this specialized conceptual language in reading and writing, in reasoning and problem solving, in guiding practical action in the laboratory and in daily life. It means learning to communicate in the language of science and act as a member of the community of people who do so. "Talking science" means observing, describing, comparing, classifying, analyzing, discussing, hypothesizing, theorizing, questioning, challenging, arguing, designing experiments, following procedures, judging, evaluating, deciding, concluding, generalizing, reporting, writing, lecturing, teaching in and through the language of science. (Lemke 1990, p. 1)

Lemke concludes that we learn to speak the language of science in much the same way in which we learn any other language: practicing it with people who master it and using it in a variety of pragmatic communicational situations, where it should be employed in its most frequent typologies, genres, and text formats.

In accordance with this theoretical perspective, students must not only understand the main concepts implicated in the theories and models and grasp the scientific vocabulary, they also have to be able to apply the necessary language structures and patterns and use the correct discursive tools and rhetorical strategies. Consequently, they must be able to distinguish and make use of the different genres of science, such as descriptions, definitions, explanations, and argumentations. Specifically related with the use of the scientific vocabulary, there is a crucial point about the meanings of words: science teachers should make bridges between the everyday meanings of terms and their meaning in specific scientific contexts. This requires acknowledging that scientists use language in very special, highly stylized ways:

> Not only is there a specialist scientific vocabulary consisting of words which are recognizably unfamiliar but there are familiar words such as 'energy', 'power' and 'force' which must acquire new meanings. Moreover, the charts, symbols, diagrams and mathematics that science deploys to convey ideas, are essential to communicating meaning and students must learn to both recognize and understand their use. The challenge for the teacher then is to introduce and explain this new vocabulary; the challenge for the student is to construct new meanings from such a language. (Evagorou and Osborne 2010, p. 136)

There are a lot of unobservable entities that science teachers have to teach in the classroom, for example, cells or electric current. The teaching of such entities depends on the use of robust representations: a cell is represented as a brick, electric current is referred to in terms of water flow, and particles are depicted as balls. All of these are metaphors, i.e., *transferences* of meaning. According to the philosopher of science Rom Harré, through this metaphorical mechanism, new vocabulary can be created within the existing structure of any given language; this process secures the intelligibility of the term in the new context of use.

Analogies and metaphors are utilized to construct and scaffold students' understandings. They are also essential components of theories and allow the generation of mental models. Such models serve the purpose of providing plausible descriptions, explanations, and predictions about real systems in nature. Based on models, students can build a special kind of evidence-based explanation to give sense to the world around them; this kind of explanation is *argumentation*:

> Work in the specialized argumentative practices of the various disciplines suggests that students not only need to write in order to master the concepts and work of a field, but more particularly to develop competencies in the specific argumentative practices of their fields [. . .]. In addition to the genre-specific writing competencies, with associated argumentative patterns, students must begin to gain a feel for the argumentative forums and dynamics of their fields. They must learn the kinds of claims people make [and] what kind of evidence is needed to warrant arguments [. . .]. (Kelly and Bazerman 2003, pp. 29–30)

Kelly and Bazerman emphasize the importance of writing and talking in the language of the disciplines within the frame of ideas known as "writing across the curriculum" (WAC). They propose to engage students in instances in which they must produce arguments in the different disciplines and beyond them. From these arguments, students learn to talk and write the language of the different scholarly fields. In their framework, these authors indicate that argumentative discourse – that trying to persuade – would be one of the communicational functions that have played a significant role in the development of scientific knowledge, hence its importance in the learning of science.

Jiménez-Aleixandre and Erduran (2008, p. 4) also highlight the importance of scientific argumentation. This competence is

> instrumental in the generation of knowledge about the natural world [and] plays a central role in the building of explanations, models and theories [. . .] as scientists use arguments to relate the evidence they select to the claims they reach through use of warrants and backings. [. . .] [A]rgumentation is a critically important discourse process in science, and that it should be promoted in the science classroom.

They also propose that there are at least five intertwined dimensions or potential contributions from the introduction of argumentation in the science classrooms (cf. Jiménez-Aleixandre and Erduran 2008, p. 5):

– Supporting the access to the cognitive and metacognitive processes characterizing expert performance and enabling modeling for

students. This dimension draws from the perspective of “situated cognition” and the consideration of science classes as communities of learners.
- Supporting the development of communicative competences and particularly critical thinking. This dimension draws from the theory of communicative action and the sociocultural perspective.
- Supporting the achievement of scientific literacy and the empowerment of students to talk and write the language of science. This dimension draws from language studies and social semiotics.
- Supporting the enculturation into the epistemic practices of the scientific culture and the development of epistemic criteria for knowledge evaluation. This dimension draws from science studies, particularly from the epistemology of science.
- Supporting the development of reasoning, particularly the choice of theories or positions based on rational criteria. This dimension draws from philosophy of science, as well as from developmental psychology.

At the same time, the Group LIEC (at the Universitat Autònoma de Barcelona in Spain) defines argumentation as a social, intellectual, and verbal activity used to support or rebut a claim; when arguing, in addition to the content of the claim, its purpose and recipients are important. In order to argue, one needs to choose between different options or explanations and to provide reasoned criteria to assess the most appropriate choices (Sanmartí 2003). In order to learn argumentative competences, Sanmartí proposes that it is necessary to promote explicit instances to teach school scientific argumentation. This means teaching what are the main traits and characteristics of this genre and practicing this skill in relation with school science content.

The research on scientific language in the classroom reviewed here has as unifying thread the hypothesis that through talking and writing science, students can access to new epistemic levels. In their school science “texts,” students give meaning to the symbols, definitions, relations, and communicative patterns that support their use of scientific models. In turn, these texts produced in the science classes are a powerful tool for the (self-)assessment of learning.

Cross-References

▶ Argumentation
▶ Discourse in Science Learning
▶ Epistemic Goals
▶ Language and Learning Science
▶ Models

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Scientific Literacy

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Originating in the 1950s, the term “scientific literacy” has been used to express diverse goals ranging from a broad knowledge of science to a particular purpose of science education (Bybee 1997). In 1958, Paul DeHart Hurd provided a clear perspective when he described scientific literacy as an understanding of science and its applications to an individual's experience as a citizen. Hurd made clear connections to the science curriculum and the selection of instructional materials that provide students with the opportunities to use the methods of science; apply science to social, economic, political, and personal issues; and develop an appreciation of science as a human endeavor and intellectual achievement (Hurd 1958). Although there have been variations, Hurd's definition expresses the application of scientific knowledge to the situations individuals will encounter as citizens. This view differentiates scientific literacy from other goals of science education.

The general use of scientific literacy has the advantage of unifying the science education community by centering on what is perceived to be the primary goal. The disadvantage of using the term is the loss of its specific meaning which was an understanding of science and its applications to personal, national, and global perspectives.

In the year 2000, George DeBoer published a historical review of the term scientific literacy. There have been numerous different goals of science education, all related to scientific literacy. DeBoer suggested a broad conceptualization of scientific literacy, one allowing for variations in curriculum and instruction. The broad goal suggested by DeBoer is consistent with earlier definitions, namely, to enhance the public's understanding and appreciation of science. Here are critical insights about scientific literacy – it is about an adult population's level of understanding and appreciation of science, it changes with time, and school experiences certainly affect the public's attitudes toward science and their disposition to continue developing their understanding and appreciation of science (DeBoer 2000).

Across the decades, there has emerged a critical distinction, between an emphasis on education for future citizens and education for future scientists. In 2007, Douglas Roberts published a significant essay in *Handbook of Research on Science Education* (Abell and Lederman 2007). Roberts identifies a continuing political and intellectual tension with a long history in education. The two conflicting perspectives can be stated in a question – should curriculum emphasize subject matter itself, or should it emphasize the application of knowledge and abilities in life situations? Curriculum designed to answer the former, Roberts refers to as Vision I, and the latter he refers to as Vision II. Vision I looks within science disciplines: it is internal and foundational. Vision II uses external contexts that students are likely to encounter as citizens (Roberts 2007).

A significant contemporary issue for those developing standards, designing curriculum, and providing professional development is recognizing the difference between the two perspectives just described. One perspective centers on disciplines such as biology, chemistry, physics, or the Earth sciences. In this perspective, programs and teaching practices answer questions such as the following: What knowledge of science and its methods should students learn? What facts and concepts from science should be the basis for school programs? In contrast, there is a *contextualist* (Fensham 2009) perspective that will begin with situations that require an understanding and application of science. When thinking about standards, curriculum, and instruction from a contextualist view, questions center on the following: What science should students know, value, and be able to do as future citizens? What contexts could be the basis for science education? The difference between these two perspectives is significant because it has implications for curriculum emphasis, selection of instructional strategies, design of assessments, and professional education of teachers. The subsequent outcomes – what students learn about science, the attitudes they develop, the skills they acquire, and their ability to competently identify, analyze, assess, and respond to life situations – also differ significantly.

The Program for International Student Assessment (PISA), an initiative of the Paris-based Organization for Economic Cooperation and Development (OECD), reinforced the original perspectives of science literacy and Roberts' Vision II in the frameworks for 2006 and 2009 science assessments. The PISA Science assessments focused on scientific competencies that clarify what 15-year-old students know and are able to do within appropriate personal, social, and global contexts.

In PISA, scientific literacy referred to four interrelated features that involve an individual's:

- Scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomenon, to draw evidence-based conclusions about science-related issues
- Understanding of the characteristic features of science as a form of human knowledge and inquiry
- Awareness of how science and technology shape our material, intellectual, and cultural environments
- Willingness to engage in science-related issues, and with the ideas of science, as a constructive, concerned, and reflective citizen (OECD 2006, 2009)

PISA Science implemented the definition of *scientific literacy* and its science assessment questions using a framework with the following components: *scientific contexts* (i.e., life situations involving science and technology), the *scientific competencies* (i.e., identifying scientific issues, explaining phenomena scientifically, and using scientific evidence), the domains of *scientific knowledge* (i.e., students' understanding of scientific concepts as well as their understanding of the nature of science), and student *attitudes toward science* (i.e., interest in science, support for scientific inquiry, and responsibility toward resources and environments).

In conclusion, for many with responsibility for national standards, curriculum materials, and assessments, the distinction between two interpretations of science literacy – "Vision I" and "Vision II" – is blurred. The dominant perceptions about the content and learning outcomes are Vision I; the principal (sometimes exclusive) emphasis is on discipline-based science knowledge and methods. An often unstated assumption is that if students understand science concepts, they will apply that knowledge to the personal, social, and global problems they encounter as citizens. That assumption could certainly be questioned. For those interested in scientific literacy, school science programs should incorporate Vision II clearly, consistently, and continually. Students should have experiences where they confront appropriate socio-scientific issues and problems within meaningful contexts. PISA Science provided an assessment model and, through backward design, the basis for curriculum and instruction for this view of scientific literacy.

Here is an essential challenge for twenty-first-century science education. Most school programs emphasize fundamental knowledge and processes of the science disciplines. These science programs are intended implicitly to provide students with the foundation for professional careers as scientists and engineers. With the centrality of science and technology to contemporary life, full participation in society requires that all adults, including those aspiring to careers as scientists and engineers, be scientifically literate. That is, they not only develop understandings of science fundamentals, they learn how to apply that knowledge to life situations.

The level of a society's scientific literacy depends on citizens' understanding, receptivity, and appreciation of science as a human endeavor with significant influence on their lives and society.

Cross-References

▶ Bildung
▶ Programme for International Student Assessment (PISA)
▶ Scientific Literacy: Its Relationship to "Literacy"

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Scientific Literacy: Its Relationship to "Literacy"

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Discussions of scientific literacy often propose answers to one or both of two distinct questions: (a) What is the meaning of scientific literacy? (b) What is the significance of scientific literacy? The first question tackles the semantic issue of how individuals in some specific group (say, a particular society) actually could, or should, use the expression. The second question deals with what is important about scientific literacy conceived in a particular way.

Meanings of "Literate" and "Literacy"

In modern English usage, the words "literate" and "literacy" have two distinct senses. "Literate" is the older of the two words, having been traced to the Latin "litteratus," meaning "marked with letters," and occurring first in late middle English in the fifteenth century. "Literacy" did not appear in usage until the late nineteenth century, which is when the meanings of the terms started to change. During most of the history of its usage, "literate" meant generally to be well educated and learned. Since the late nineteenth century, it has also come to refer to the abilities to read and write text. The transition in meaning that began slightly over 100 years ago has had such an effect that the Oxford Dictionary of English in 2012 reported "ability to read and write" as the primary meaning of literacy and "having education and knowledge typically in a specified area" as the secondary meaning.

Conceptions of Scientific Literacy in the 1950s and 1960s

In the field of science education, it is the second of the Oxford Dictionary of English usages that usually is found: that is, scientific literacy referring to being educated and possessing knowledge in science and about science. The term appeared in the science education literature during the middle of the twentieth century, being used by American-based scholars to express the need to increase attention to science education. Early uses of the term were by McCurdy (1958) and Hurd (1958). McCurdy's desire was for an understanding of natural science to be part of a broad liberal education, in particular, to help allay confusions between science and technology that he saw as widespread in American society of the day. He sought a science course at the secondary school level that provided knowledge both of and about science through "familiarity with the history and accomplishments of science and its relation to the matters of everyday life . . . [and] emphasis upon the cultural roots and goals of science" (p. 369). Hurd saw the achievements of science as the defining characteristic of a modern society and took an "acquaintance with scientific forces and phenomena [as] essential for effective citizenship" (p. 13). He sought a science education both for continued scientific advancement and for enabling people to cope with change.

He recognized the enormous difficulty involved in selecting from the "tremendous volume of scientific knowledge and concepts" (p. 15) the small proportion that could be taught. His attention was more focused on learning experiences that foster "the development of an appreciation of science as an intellectual achievement, as a procedure for exploration and discovery, and which illustrate the spirit of the scientific endeavor" (pp. 15–16).

These early writers about scientific literacy all sought greater understanding both of and about science for members of society as a whole. This desire expressed their semantic notion of scientific literacy. Their reasons for seeking this goal expressed the values that they held for scientific literacy: the promotion of effective citizenship, the broadening of liberal education, the successful continuation of scientific achievements, the preparation to cope with a rapidly changing society, and the appreciation of and support for science.

By the mid-1960s, Pella et al. (1966) was able to define scientific literacy as "science for effective citizenship" (p. 199). This definition is skewed neither toward the sense of being knowledgeable in science nor toward the sense of being able to read science. Rather, the definition speaks more to the goals of pursuing scientific literacy than to what scientific literacy actually means. This coupling of goals to meaning became very common in discussions of scientific literacy over the past 50 or so years. Scientific literacy has become a programmatic concept, which is used not only to express meanings but also to urge particular educational objectives to reach favored moral and political ends. Pella traced the meanings of scientific literacy – science for the citizen and science for general education – through the two previous decades. He concluded that "The scientifically literate individual presently is characterized as one with an understanding of the (a) basic concepts in science, (b) nature of science, (c) ethics that control the scientist in his work, (d) interrelationships of science and society, (e) interrelationships of science and the humanities and (f) differences between science and technology" (p. 206).

Concern with Practical Problems

In the literature of the latter part of the twentieth century, most of the themes identified by Pella were maintained. However, many scholars began to think that scientific literacy conceived as such was disconnected or too far removed from the lives of nonscientific citizens. Thus, in addition to the focus on knowledge and understanding that was predominant in Pella's time, there emerged a growing concern with the possession of the kind of knowledge, understanding, and competence required to deal with practical problems that are science related, harking back to the early idea of science for effective citizenship. Discussions turned to such matters as the following: the ability to think scientifically about natural phenomena and to find answers to questions about them; the ability to use scientific knowledge and scientific ways of thinking in problem solving and in making informed decisions about one's well-being and that of others; the knowledge needed for intelligent participation by the nonscientific citizen in science-based social issues, including the knowledge needed to understand the issues and the communicative competence to reason about such issues with others and as they appear in various media; and the ability to think critically about science and to deal with scientific expertise, including the ability to make plausible assessments of risks, to formulate and evaluate positions on matters informed by science, and to offer and to assess arguments based upon scientific evidence to support those positions.

The Primary Sense of Scientific Literacy

Another line of thought, focusing scientific literacy on practical problems, that began to develop late in the twentieth century was that participation in public discourse about science-related issues requires an ability to interpret oral and written language and perhaps also to write on science-related issues. This recognition was the beginning of a turn in thinking about scientific literacy toward the primary sense of literacy, the ability to read and write. An early mention of scientific literacy in this primary sense was by Branscomb (1981), who in fact wanted scientific literacy to be understood broadly and was fearful that it might be defined "narrowly as the ability to read and write [science]" (p. 6), which in her view would exclude a large proportion of the population that relies on modes of communication other than text to gain information. In the science education field, early attention to the primary sense of scientific literacy was manifested in a special issue of the *Journal of Research in Science Teaching* (1994, Vol. 31, Issue 9) on the "reading – science learning – writing connection." In the ensuing nearly two decades, several variants have emerged of how the primary sense of literacy is related to scientific literacy.

Reading and Writing as a Central Scientific Practice

Scientists read a great deal. Evidence has shown that scientists derive most of their information through reading and read for nearly one-fourth of their total work time. Evidence also shows that scientists rate reading as essential. The award-winning and high-achieving scientists tend to read more than others. When writing time is factored in, scientists spend almost one-half of their working time involved in primary literacy activities. Science educators thus have begun to see reading (and writing) as core scientific practices. This change of perspective on the nature of science led educators to rethink the view that hands-on experience is *the* essential core of scientific practice and, as a result, the sine qua non of any respectable science curriculum. Once the view of scientific practice is altered to make room for literacy in its primary sense, failure to attend to reading and writing in science learning was interpreted as neglectful. Thus, by the turn of the millennium, several research programs were underway designed to develop an understanding of specific literacy practices that underlie science to incorporate those practices into science teaching and learning.

Reading and Writing as a Tool for Doing Science

Once the amount of time scientists spend reading and writing is recognized, the question naturally arises of the relationship between literacy and science. Observation, for example, has been seen as a defining feature of science, grounding its empirical character, and being used to distinguish science not only from creationism but also from philosophy and literature. In contrast, literacy practices often have been seen as tools scientists use to help them do science, as opposed to essential features of the nature of science. Thus, scientists might be described as readers and writers in order to accomplish their task of doing science, and students might be taught to read and write science as tools for learning science. The idea here is that the reading and the writing are not conceived as part of science itself, whereas, for instance, observation is.

Reading and Writing Science as Important for Effective Citizenship

Reading and writing science can be seen as important in science education because they afford citizens access to understanding articles about science in various media, including newspapers, magazines, television, and the Internet. The type of reading and writing seen as desirable is usually described as "critical," because the emphasis is on critically evaluating the conclusions contained in popular reports of science, communicating the substance of those conclusions to a third party, and engaging in social conversation about their validity. In contrast, the evidence overwhelmingly shows that students at all levels and the nonscientific public have difficulty interpreting such reports of science, even though they think the reading is easy. Their misjudgment has been traced to a method of literacy instruction in schools, colleges, and universities that emphasizes the recognition of words to the detriment of interpreting meaning.

Reading and Writing as Important to Learning the Nature of Science

The manner of language use helps define the nature of the practice. In school science textbooks and classroom instruction, language is used mostly to show, summarize, and define; to present facts and descriptions; and to develop vocabulary and descriptive accounts of natural phenomena. In science itself, language is used to demonstrate conclusions, to provide reasons for why things are as they are, and to argue for causal interpretations. During the first decade of the twenty-first century, science education scholars began to urge the point of view that science instruction can profitably capitalize upon the common epistemological footings of science and reading. Both science and reading involve inquiry, that is, analysis, interpretation, and critique. Thus, if science students are taught to interpret the meaning of science texts, to distinguish in those texts what is reported as observed from what is inferred, to identify the evidence offered for conclusions and the conclusions drawn on the basis of evidence, and to understand the descriptions of methodology, then through learning the nature of reading and writing science texts, the students will have learned something of the nature of science.

Reading, Writing, and Text as Constitutive of Science

A growing recognition in the first decade of the twenty-first century is that the two senses of scientific literacy cannot be understood independently. That is, there is no possibility of learning science without learning the literacy practices of science. The literacy practices are partly constitutive of science. Just as it is impossible to think of science absent its empirical character, the argument goes, it is impossible to think of science without its literacy character. That literacy character comprises all of the practices involved in producing and interpreting scientific texts, which are jointly and succinctly referred to as reading and writing in science. Therefore, it is impossible, according to this viewpoint, to be scientifically literate in the sense of having education and knowledge in science without being able to read and write science to a commensurate degree.

Cross-References

- ▶ Language and Learning Science
- ▶ Reading and Science Learning
- ▶ Scientific Literacy
- ▶ Writing and Science Learning

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Scientific Values

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Science plays perhaps the most important role in the understanding of the universe. Science moreover contributes to the formation of values that effect social values. Therefore, there are many important characteristics and values that must be considered in scientific activities. Scientific outputs produced under the light of scientific values are important and scientists value these outputs. The fundamental value that must be obeyed by scientists in their research is honesty. The scientist has to report her/his experimental results without any falsificitation. The scientist must report the results with exact and understandable statements and must give detailed information about the materials and methods which are used in the research. The scientist before carrying out scientific research should not expect any commercial contribution from the research. The scientist must pay attention to the results of scientific research that contributes to humanity.

The scientist should also pay attention to the possible negative effects of research. In order to transform the research by scientists into real scientific values, there are many and extra important rules which must be followed by the scientists: reliability, testability, accuracy, precision, generalizability, and the appropriate statistical methods (Allchin 2012).

First of all, for turning scientific research into real scientific values, the research that is carried out has a novelty and it should not be a repetition of previous scientific research. In addition, the scientist should report all scientific results without fragmentation. When the scientists write their scientific research reports, they should write original statements and always properly cite the research of others. At the present time, the language of most of the platforms, the scientific journals, where the scientific researches are published, is generally English. This situation sometimes causes problems for scientists whose native tongue is not English. Even scientific research that is well designed and achieves important results can be rejected by the journal peer review process when the English is substandard. As a result, the language of the scientist can cause serious delays in the publication of valuable scientific research.

Another important parameter that the scientist should pay attention to is the use and evaluation of appropriate statistical tools and methods for the numerical values obtained from scientific researches. It is very well known that the different results can easily be obtained from different statistical methods. Therefore, the scientists should know detailed information on the statistics. When the scientist reports scientific research, there are general rules to be obeyed. For example, in the introduction part, the current literature should be summarized, and the gap within current literature should be defined very well. In the materials and methods part, the scientist should give details about materials and methods that they used. Sometimes, in scientific papers, researchers give appropriate citations to methodological papers instead of writing detail on the methods. As it is mentioned above, the results should be given exactly and without any falsification.

The scientist should pay attention to the effects of observer and also placebo effects. Therefore, especially in drug design researches, double-blind control groups should be used (Allchin 2012). Results should be compared with current literature knowledge and the reasons of parallel and nonparallel results should be explained. Novel findings must be emphasized and explained as a guide for other scientists interested in carrying out similar investigations. Research must be presented in peer-reviewed journals, but reviews must be based solely on scientific value, not influenced the personal characteristics of the researchers such as nationality, race, and religion. The evaluation should be objective. Therefore, to prevent any bias, the referees should be blind to authorship. Thanks to these values, science continues to improve our understanding of the universe and to the improvement of our lives.

Cross-References

- ▶ Cultural Values and Science Education
- ▶ Socioscientific Issues
- ▶ Values in Science

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Scientific Visualizations

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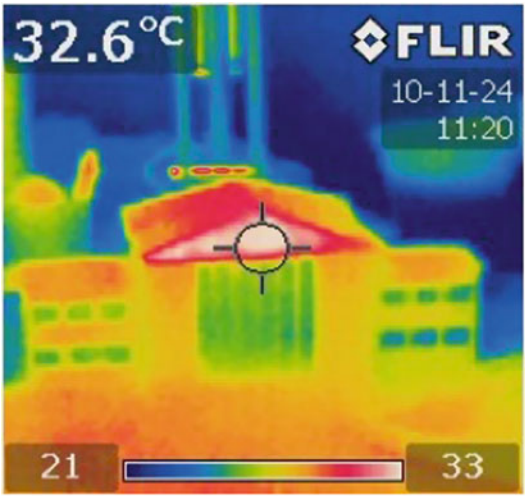
Keywords

Animation; Dynamic visualization; Simulation; Static picture

Scientific Visualizations

Visualization refers to either an internal or external representation of a concept, process, information, problem, or idea. Internal visualization encompasses a mental process whereby a person imagines some graphical or pictorial representation of information. An external visualization refers to an object or artifact that represents information graphically, pictorially, or sculpturally and may contain auditory or tactile elements. External visualizations can amplify the use or acquisition of knowledge by presenting large quantities of complex information visually. Both internal and external visualizations play important roles in science education in terms of representing science content, science processes, and the nature of science (Gilbert 2005). Indeed, researchers have argued that the mismatch between students' internal representations and the external ones presented in class or textbooks may account for some of the challenges in science instruction. Hence, much attention has been given to the careful design and application of external visualizations that are accessible to students and supportive of learning and instruction.

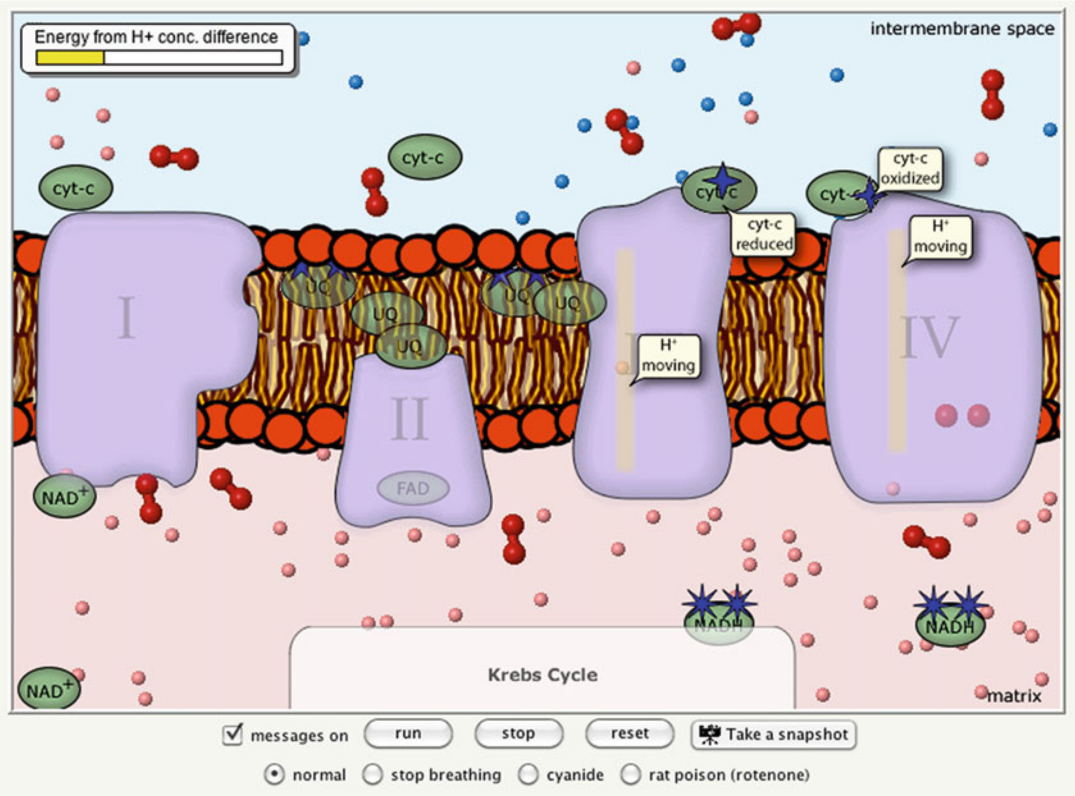
External scientific visualizations (henceforth scientific visualizations) can be used to communicate ideas and concepts and typically employ computer-based methods to represent theoretical concepts or physical data (e.g., from molecules, the human body, the Earth). Visualizations can serve to make abstract processes or concepts more explicit and concrete or to illustrate concepts that occur on very small (e.g., microscopic) or very large (e.g., astronomical or geological) scales. Instead of presenting complex data as sequences of numbers or text, scientific visualizations present data pictorially and graphically to take advantage of the human ability to process information and detect patterns through visual perception (Fig. 1).



Scientific Visualizations, Fig. 1 Infrared visualization of a model home (Image courtesy of Charles Xie)

Scientific visualizations can be grouped into three types: static, dynamic, and interactive visualizations. Static visualizations (i.e., images or graphs) do not change over time and do not allow any direct user manipulation. Typical static visualizations used in science include graphics, models, and diagrams found in research articles, journals, or presentations (for scientists) or in textbooks or lecture slides (for science students). Examples of static visualizations used in science education are models of atomic structure, pictures of organelles, or temperature isobars over a region of a country. Dynamic visualizations, or animations, do change over time or with user manipulation, resulting in the depiction of motion or progression. Examples of dynamic visualizations include animations of cellular processes, chemical reactions, or weather patterns.

Interactive visualizations differ from dynamic visualizations in that they are designed to be manipulated by the user, who thereby influences what the visualization presents. Simple interactive visualizations contain controls that enable the user to stop, start, replay, or step through an animation or sequence of static pictures. Complex interactive visualizations, like simulations or virtual experiments, are based on underlying computer models that enable users to change variables, parameters, or settings and explore resulting behaviors, dependencies, or outcomes (Fig. 2). For instance, a complex interactive simulation of electromagnetism might enable the user to change the "charge" settings and placement of



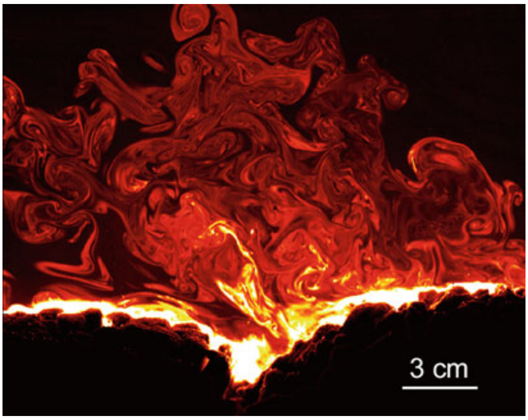
☑ messages on

● normal ○ stop breathing ○ cyanide ○ rat poison (rotenone)

Scientific Visualizations, Fig. 2 Molecular Workbench simulation of cellular respiration that enables students to experiment with different settings (normal breathing, no breathing, cyanide, and rat poison) (Image courtesy of Charles Xie)

objects, resulting in observable changes to the electric field throughout the system. These visually rich, interactive visualizations enable students to construct their own understandings of complex phenomena by manipulating phenomena or processes that would otherwise be difficult or impossible to achieve in science classrooms.

Although scientific visualizations were first advanced as tools for practicing scientists, they have been adapted to help science students learn concepts and inquire about the world around them. For example, a scientist may use a dynamic visualization of fluid flow over coral reefs (Fig. 3) to communicate results about how corals exchange nutrients with the water; but students might use the same visualization (or a slightly simplified version) to learn basic



Scientific Visualizations, Fig. 3 Scientific visualization of fluid flow used to investigate how corals exchange nutrients with the water (Photo courtesy of Matthew Reidenbach) concepts of fluid dynamics. Students can gain practice in inquiry processes by making observations and inferences about visualizations and can learn to analyze data from the visualizations for purposes of addressing research questions. For example, learners might investigate infrared images of different conductors to explore questions about heat transfer. They might draw certain inferences or explanations from one set of images but could arrive at different conclusions when presented with a second set of images. Such investigations would support the development of inquiry skills as well as new understandings of the nature of science.

Different types of visualizations provide distinct affordances or opportunities for learning. Static visualizations provide students with concrete images of scientific concepts that might otherwise be too abstract, too large, or too small to be directly observed. For instance, static visualizations of electron orbitals can help students understand atoms, even though such orbitals are not actually perceivable, and only exist in a statistical sense. Importantly, such representations could also promote faulty interpretations, and developers of such materials must be sensitive to possible alternative interpretations that learners might derive. Students can refer to or engage with scientific visualizations at their own pace, returning multiple times, asking different questions, or debating their interpretation with peers or instructors.

Dynamic visualizations are often used for purposes of representing inherently dynamic processes such as rotations of molecules, DNA replication, or planetary motion. Dynamic visualizations can help students learn about complex scientific processes on very small or large scales that may not be easily communicated through sequences of static images. For instance, animations of cells dividing could help students understand the biological process of mitosis, or animations of electron movement in conductors could help students develop an understanding of electric current. As in the case of static visualizations, learners can make observations and inferences about dynamic visualizations and analyze that data to answer their questions and develop understandings about the nature of science. For example, two students looking at the same dynamic visualization might notice completely different events, which could lead to a discussion of how two scientists might differ in their interpretation of phenomena or experimental outcomes.

With simple interactive visualizations, such as visualizations with interactive controls, students can learn content at their own pace. For example, students using an interactive visualization of a cell can click on various organelles to obtain more information about the purpose of each organelle. This self-paced interaction allows learners to reach a better understanding as compared to just watching an animation passively. Complex interactive visualizations, such as simulations, provide a more extensive range of manipulations that can allow students to test their ideas, explore various conditions, and build a personal understanding of the relevant science concepts. Students can make predictions, test their ideas using the simulation, and receive feedback from the simulation itself that helps them consider revisions to their ideas or hypotheses. Simulations enhance inquiry-based approaches to science teaching, as students can engage in experimentation by manipulating variables and conducting virtual trials. For instance, in a simulation of natural selection, students could introduce mutations and explore their impact on population survival – something that is nearly impossible to do without interactive visualizations. Simulations can also contribute to an understanding that there is not “one” scientific method, as students may use multiple approaches to address the same research question.

Limitations of visualizations involve the inherent barriers of their particular representations. Static visualizations, for example, do not enable students to interact with the visualization and do not provide direct representation of dynamic processes. Simple dynamic visualizations that do not enable students to interact may result in students passively watching the animation without actively engaging with the information. Interactive visualizations enable learner control, but without adequate self-regulatory or self-monitoring strategies, learners may not take full advantage of the interactive affordances for learning. Visualizations are also limited to varying degree in the quality of their renderings, the complexity, or abstraction of information presented. Conceptual errors may have been introduced by attempts at simplifying scientific concepts.

Merely providing a learner with a visualization – whether static, dynamic, or interactive – does not guarantee that the targeted concepts will be communicated or learned. Research on learning with scientific visualizations highlights the importance of the design of the visualization, the design of supporting instruction, and the role of prior knowledge of the learner. Decreasing the unnecessary or distracting information while highlighting salient information will improve the accessibility and efficacy of any scientific visualizations (cf. Tufte 1990). Visualizations should be surrounded by supporting instruction that encourages students to make connections to existing ideas, reflect on their understanding, and revise their ideas. Instruction should also discuss limitations of any visualization employed, and what the visualization does and does not represent. For example, many images of atoms are presented in textbooks without explicit discussion regarding the limitations of the visualization. As a result, many students believe that we can actually see atoms directly, that atoms have color, that electron orbits have color and shape, and that chemical bonds are material objects – since they are often depicted as lines.

As with all instructional elements, students' prior knowledge will greatly influence what they learn from scientific visualization. For example, a visualization of cell processes may help a high school biology student to understand those processes more deeply, whereas a sixth grader might fail to understand the scientific content of the same visualization. Thus, design of both the visualization and the supporting instruction should pay careful attention to the expertise level of the intended audience. Pedagogical supports, such as lesson plans and assessments, and teaching notes, would also be important, to help teachers and learners derive the greatest advantage from visualizations.

Cross-References

- ▶ Digital Resources for Science Education
- ▶ E-Learning
- ▶ Models
- ▶ Multimedia Videos and Podcasting
- ▶ Multimodal Representations and Science Learning
- ▶ Online Media
- ▶ Representations and Learning in Science
- ▶ Science and Technology
- ▶ Simulation Environments
- ▶ Technology for Science Education: Research
- ▶ Visualization and the Learning of Science

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Scientist-School Interactions

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Keywords

Informal science education; Partnerships; Science outreach; Scientists in Schools

Nature of Scientist-School Interactions

There are numerous ways in which scientists and other professionals working in science-related fields interact with schools to add value to formal science education programs. Some interactions are longer-term, ongoing relationships, while others are single occurrences. The nature of interaction varies widely and includes face-to-face visits as well as online interactions such as e-mail, Skype, blogs, discussion forums and chat rooms, or a combination of these. Some organizations and professional associations become involved so that their scientists can deliver specific outreach programs into schools. Universities may encourage their faculty to become involved in an attempt to attract more students to enroll in undergraduate studies at their institution. Particular industries may participate because they wish to encourage students to pursue science-related careers leading to employment in their field. The proportion of schools that have interactions with scientists is difficult to estimate but is almost certainly underrepresented in the literature because of the many interactions that are established through ad hoc, personal connections, such as a scientist being a parent at a particular school.

Scientist-school interactions may involve scientists working directly with students, teachers, or both. Types of interactions include a scientist presenting to a class or a number of classes; delivering a unit of work in conjunction with a teacher; mentoring students in open-ended science investigations; judging science fairs or other student work; participating in school science camps; supervising students or teachers undertaking research projects or work experience in the scientist's workplace; arranging student excursions to the scientist's workplace; assisting teachers, especially in primary or elementary schools, to identify and embed science in themed units of work; providing teacher professional development; and providing resources such as equipment or consumables.

Purpose

Regardless of the type or method of interaction, the broad purpose of involving a scientist with a school is to expose students to contemporary, real-world science and the work of science professionals. More specific aims are to stimulate and increase students' interest in studying science, increase students' awareness of careers in science, update teachers' knowledge of contemporary science, and increase awareness of the social and economic importance of science to the community. A secondary purpose, more commonly in primary or elementary schools, is to increase the profile of science in the school. Effective scientist-school interactions deliver successfully on these aims.

Contributions and Benefits

All scientist-school interactions share one distinguishing feature – the human element. For this reason they not only provide effective contributions to science content understanding but also demystify the image of scientists as being somehow different from ordinary people. Working directly with a scientist provides a unique, personal insight for students and teachers that is difficult to replicate with other curriculum experiences or programs.

The benefits of scientist-school interactions for the individuals directly involved have been well documented, and while the benefits for students and teachers may be obvious, the benefits for scientists are also significant. Benefits for students include increased engagement in science, the opportunity to see scientists as real people, having fun, increased awareness of careers in science, increased knowledge of contemporary science, and increased awareness of the nature of scientific investigation. Benefits for teachers include enjoyment from working with a scientist, updated knowledge of contemporary science, increased engagement by their students, increased confidence in teaching science, and increased profile of science in their school. Benefits for scientists include enjoyment from working with students and teachers, increased satisfaction with their own career, and increased confidence in communicating science. Scientists with school-aged children also report an increased knowledge and understanding of the school system as a benefit for themselves.

Characteristics of Effective Scientist-School Interactions

The success of scientist-school interactions depends on a variety of factors including thorough planning and preparation by the teacher so that the interaction, whether a single visit or ongoing relationship, forms part of a curriculum program; clear, mutually respectful communication between the scientist and teacher to clarify expectations of each other; the ability of the scientist to engage with students and teachers; and the flexibility of both parties to adapt as required. The question of whether longer-term, ongoing relationships are more effective than once-off, single interactions is worth considering. There is little on this topic in the literature, perhaps because longer-term interactions are not especially common due to the greater investment in time and effort that is required to sustain them. One of the documented characteristics of longer-term interactions is that the students and teachers develop a rich relationship with the scientist. This leads to additional benefits that range from simple efficiencies such as the scientist being able to find their way around the school through to the interaction adapting and becoming more refined as each party gains confidence and learns from previous experience.

Cross-References

► Citizen Science
► School-Community Projects/Programs
► Science Community Outreach

Secondary Science Teacher Education

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Keywords

Knowledge; Learning; Science Teacher Education; Strategies; Teacher Education

Introduction

“We teach as we were taught.” These six words summarize the major challenge facing secondary science teacher education, both from the perspective of what science we teach and from the perspective of how we teach science at the secondary level. The tendency of new and experienced teachers to teach as they were taught has been recognized for decades. Less frequently discussed and explored is the tendency of science teacher educators to teach as they were taught. We now know from research a great deal more about so-called best practices and about how individuals learn. Unfortunately, it is simply not enough to present best practices and new insights into learning to new teachers as information. As they themselves struggle to find their pedagogical feet in practicum classrooms and early in their teaching careers, new teachers need to learn from experience as they also learn how to learn from experience. Secondary science teacher education requires carefully developed strategies for helping new and experienced teachers to change their teaching *habits* – acquired by watching their own teachers – as they change their teaching *frames*, the ways they typically think about how students learn science.

The Content of Science: What We Teach

Typically, the science content to be taught is set out for teachers in curriculum documents that differ from state to state and province to province. Each jurisdiction usually sets out additional requirements for attention to the processes of science as well as the content. In the context of secondary science teacher education, those learning to teach face the challenge of connecting science content to the everyday world of their students. Studying science in university courses in order to perform well on examinations is quite different from processing science content in ways that illuminate events in the world around us and help others to learn basic scientific concepts. Secondary science teachers also struggle with the tension between preparing a few students for further study of science and preparing all students for the understandings of science that help them see how biology, chemistry, physics, and earth and space science provide insights into everyday events from infections and reactions to collisions and earthquakes.

The Process of Science: How We Teach

Science teacher educators have focused for decades on issues associated with teaching science as inquiry and learning science for understanding of concepts rather than memorization of facts. Some universities have established groups that study how first-year university students learn a science subject; such research groups tend to focus on a single subject – biology, chemistry, or physics. These groups produce articles offering insights into the learning approaches and difficulties of first-year university students, and those insights can tell us a great deal about the learning achieved by senior secondary students who have gone on to university study. Knight (2004) has produced an outstanding analysis of the teaching of physics topics to first-year university students. His five recommendations (they are not easy to enact) should apply to all first-year university science teaching and certainly have implications for secondary science teaching:

1. Keep Students Actively Engaged and Provide Rapid Feedback.
2. Focus on Phenomena Rather than Abstractions.
3. Deal Explicitly with Students' Alternative Conceptions.
4. Teach and Use Explicit Problem-Solving Skills and Strategies.
5. Write Homework and Exam Problems that Go Beyond Symbol Manipulation to Engage Students in the Qualitative and Conceptual Analysis of Physical Phenomena (Knight 2004, pp. 42–45).

In this list we see clear and focused advice that reflects careful analysis of recent research on learning as well as Knight's study of his own teaching of physics students in their first year of university study. The advice is directly relevant to secondary science teaching. Each of his five lessons invites secondary science teachers to look carefully at their own teaching and at the learning of their students. This invitation is equally important for science teacher educators, who must consider whether or not this advice to science teachers can be applied to the work of preparing individuals to teach science at the secondary level. Knight's five lessons need to be modeled explicitly to beginning science teachers in order to provide them with personal experience of their impact on learning. The *phenomena of teaching and learning* tend to be more engaging than educational abstractions, and qualitative and conceptual analysis of *educational* phenomena certainly have an important place in secondary science teacher education. Teaching guided by Knight's advice is inherently complex and challenging. Modeling these principles and making it explicit that one is doing so is similarly complex and challenging; explicit analysis of one's own teaching as a science teacher educator may have more impact than any other strategy used with future teachers of secondary science.

Science Teachers' Knowledge of Practice

An important set of recommendations for secondary science teaching and teacher education appears in Loughran's (2010) consideration of the work of expert teachers. Drawing in part on his knowledge of the teaching insights developed within the Project for Enhancing Effective Learning (http://peelweb.org), Loughran presents six elements of expert teachers' knowledge of practice: prior knowledge, processing, linking, translation, synthesizing, and metacognition. Like so much recent research, Loughran highlights the importance of identifying and responding to students' prior knowledge; again, this is a significant consideration for science teacher educators. Processing, linking, translating (moving ideas from one context to another), and synthesizing are important elements of science teaching; the corresponding challenge for science teacher education is to incorporate these elements into the preservice teacher education experience in ways that provide those learning to teach with opportunities to practice and thereby develop appropriate skills for teaching. Finally, metacognition is a crucial element of secondary science teacher education. New teachers need to be able to regulate and monitor their own professional learning, and they need to develop skills for encouraging their students to become similarly attentive to their learning of science. To encourage these elements of expert teaching in our secondary science classrooms, they must be included within the learning experiences of teacher education for secondary science.

The Importance of Prior Knowledge in Learning to Teach Science

Much has been written about the importance of teachers' identifying and responding to views of scientific phenomena that students hold when they begin a course in science. Much less attention has been given to the views of educational phenomena that prospective teachers hold when they begin a course in learning to teach science. Insights into one classroom of secondary science teacher education are provided in Bullock's (2011) fine-grained analysis of the learning experiences of five individuals in a physics curriculum methods course in a 1-year initial teacher education program. The focus of the analysis is on how learning in the methods course related to and interacted with learning in practicum settings. The participants in the study were interviewed four times through their program, first in a focus group and then individually to explore more fully the views expressed in each focus group. This unique study of science teacher education illustrates clearly and powerfully that the prior knowledge (including teaching habits and frames of mind for thinking about teaching and learning) that a prospective teacher brings to a science teacher education program is a major influence on what that individual takes from the program. Gone are the days when science teacher educators might assume that all their students leave their classes with the same messages, including the ones that they were trying to develop and convey.

Learning to Identify the Effects of Teaching on Students

Education generally and teacher education in particular often appear to be short on knowledge of what works in practice. While there is much discussion of evidence-based best practices, that discussion is rarely accompanied by consideration of the complexity of changing personal teaching practices, which are typically habitual. Hattie's (2012, p. ix) central message is "Know thy impact," and this message is as important for science teacher educators as it is for science teachers. Hattie's own words speak clearly. "A major theme of this book... is that the quality of teaching makes all the difference." "The message in this book is that teachers, schools, and systems need to be consistently aware, and have dependable evidence of the effects that all are having on their students – and from this evidence make the decisions about how they teach and what they teach" (p. 149). "What is asked for here is a culture in which teachers spend more time *together* pre-planning and critiquing this pre-planning, and working in teacher groups to interpret the evidence about their effect on students" (p. 168).

These messages come from an individual who has studied research on teaching and learning for many years and who is urging us to place the emphasis on evidence of the effects of our teaching on our students' learning. These messages have more significance for science teacher educators than for science teachers in secondary schools; those whose work it is to prepare individuals to teach science at the secondary level need to gather continuously the evidence that they are encouraging, challenging, and enabling new science teachers to develop habits of practice and frames of mind that permit them to know their impact on the students they teach. Hattie's approach has several unique features. While it is important to work from the empirical evidence available about a range of teaching practices, Hattie stresses the importance of gathering evidence of the effects of one's teaching in one's own classroom and working with other teachers in one's school or college of education to interpret that evidence and collectively plan further development of teaching practices.

The Importance of Experience: Metacognition and Transformative Learning

Mezirow's (1997) theory of transformative learning has significant implications for secondary science teacher education. Just as secondary science teachers seek to transform students' common-sense views based on personal experience into richer and deeper understandings based on principled analysis of scientific phenomena, so secondary science teacher educators seek to transform prospective teachers' common-sense views of teaching and learning into richer and deeper understandings based on principled analysis of classroom events. Three common themes in the theory of transformative learning are the centrality of experience, critical reflection on that experience, and rational discourse as a means of learning. Experience is seen as socially constructed, so that it can be deconstructed and acted upon. It is experience that provides the grist for critical reflection. Major challenges for secondary science teacher education and teacher education generally continue to be the development of skills of critical reflection on practicum experiences and the linking of those experiences to what is presented in education courses.

Having experience and learning from experience are obviously related yet they are not the same. Without careful analysis and discourse with others, what we learn from experience is likely to be both incomplete and flawed. Just as everyday experience with natural phenomena often leads to incomplete and incorrect understandings, so everyday experience of students in classrooms leads to incomplete and incorrect understandings of why teachers display particular habits in their teaching. Identifying assumptions and developing links between theory and practice are some of the many activities that fall under the term *metacognition*. Those learning to teach have rarely been challenged to become metacognitive and thereby come to understand the nature of their own learning processes. The end goal of transformative learning is professional autonomy, and secondary science teacher education needs to promote this goal at every opportunity.

Overview

To summarize, secondary science teacher education shares many of the challenges and responsibilities associated with teacher education generally. Because science considers the phenomena of the natural world, science teachers can provide many firsthand experiences to their students to help them to refine and extend the views they have developed from prior experiences. Secondary science teacher education has the additional responsibility of providing experiences that will enable future science teachers to consider the phenomena of the educational world. Becoming metacognitive about one's own learning and the learning of others is central both to learning secondary science and to learning to teach it. We often teach as we were taught because the habits of teaching and learning and the frames of mind for education that we developed as students observing our own teachers tend to be stable and difficult to change. For science students, science teachers, and science teacher educators, reframing our perspectives and developing new habits go hand in hand. The parallels between learning science and learning to teach science are numerous and significant. The research on learning in general and learning science in particular offers challenging insights that can help shape new and transformative science teacher education practices that move beyond teaching as we were taught.

Cross-References

- ▶ Biology Teacher Education
- ▶ Chemistry Teacher Education
- ▶ Environmental Teacher Education
- ▶ General Science Teacher Education
- ▶ Inquiry, Learning Through
- ▶ In-Service Teacher Education

- ▶ Language in Teacher Education
- ▶ Metacognition and Science Learning
- ▶ Pedagogical Content Knowledge in Teacher Education
- ▶ Pedagogy of Teacher Education
- ▶ Physics Teacher Education
- ▶ Project for Enhancing Effective Learning (PEEL)
- ▶ Science and Mathematics Teacher Education
- ▶ Science and Society in Teacher Education
- ▶ Self-Study of Teacher Education Practices (S-STEP)
- ▶ Student Teacher as Researcher
- ▶ Student Teachers' Needs and Concerns
- ▶ Teacher Professional Development

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Self-Efficacy in Learning Science

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Keywords

Capacity beliefs

Self-Efficacy Beliefs for Science Teachers and Students

Teachers and students hold beliefs about their capabilities for teaching and learning science. These self-perceptions about personal abilities to manage engagement with science have been shown to causally influence success through motivation and the ability to do what is necessary in a given science learning environment. Such beliefs are known as self-efficacy beliefs and are different from more general beliefs of self-confidence and self-esteem in that they are targeted at specific future performance. Since all self-efficacy beliefs, including those for teaching and learning science, are malleable and have a causal relationship to success, it can be useful to include them in strategies to improve science education.

Self-efficacy study is rooted in Bandura's (1997) social cognitive theory and is composed of two dimensions: efficacy predictions and outcome expectations. These reflect the position that personal expectations of competence are tempered by the affordances of the context in which an individual will act. If a teacher or student expects that the environment in which they will teach or learn science will allow them success, then their chances of achievement are more likely (Dolin and Evans 2011). Conversely, when various factors exist which may inhibit successful science learning, then personal self-efficacies may be diminished. Studies show that while higher self-efficacies, motivation, and confidence to teach science often result from professional development, contextual outcome expectations may not be similarly elevated. For experienced teachers this may indicate a realistic assessment of the intractability of local teaching conditions including the perceived chances of actually making a difference with given students. Another explanation of increased self-efficacies and static outcome expectations after teacher development could be the inexperience teachers have at teaching with their newly increased capacity beliefs. Consequently, even though social cognitive theory includes both dimensions of self-efficacy (efficacy predictions and outcome expectations), studies also often look at the two constructs separately so that changes in efficacy predictions can be seen when different from outcome expectations.

High self-efficacies increase teacher and student motivation and success with teaching and learning science. Both are more likely to take risks, accept challenges, and try new ways of doing science when their self-efficacies are high. One of the most common uses of self-efficacy in science teaching over the past 20 years has been to gauge change in capacity beliefs during preservice methods courses and teacher professional development programs. A notable finding has been that an increased use of inquiry-based instruction of professional development is correlated with increases in self-efficacy (Dolin and Evans 2011).

Ameliorating Self-Efficacy

Given this potential, it is useful to know how personal self-efficacies are created and changed. Bandura (1997) describes four ways through which they naturally develop. Primary is the accumulation of **mastery experiences** relevant and specific to a future event through which we develop a sense of the likelihood of successful performance. When teachers have reasonable success with trying unfamiliar science teaching methods, they are more likely to predict that they will also experience some success at other methods they have not tried. Conversely, when students experience repeated failure when attempting to design an experiment with adequate controls, they will predict their continued failure and resist future attempts with such experimental design.

Another method by which self-efficacies are changed is through **vicarious experiences** where students may see peers similar to themselves competently conducting a science exploration and consequently feel that perhaps they too can do the same. This comparison with successful others raises their perceived self-efficacy at such tasks and means that they are more motivated to attempt explorations and more likely to do so competently. Conversely, a new teacher may hear from another science teacher that facilitating group work is not only difficult but likely to result in a loss of control over the classroom behavior. This message from someone the teacher compares themselves to may diminish their self-efficacy for using group work so that they may be more reluctant to attempt it.

The self-efficacies of both teachers and students are also affected by **social persuasion** from peers as well as from feedback to one another. When authentically encouraged or discouraged about their ability to facilitate or participate in a given science activity, teachers and students are more or less likely to be motivated to become engaged and their consequent success affected. The credible feedback which teachers can give to students about their ability to succeed at a specific science activity can significantly influence student self-efficacies and consequently their achievement. Likewise, genuine student feedback to teachers about their efforts can persuade teachers to attempt teaching strategies that may be new or uncomfortable to them.

Teachers and students partly use judgments of their own **physiological and emotional states** to decide how confident about a specific future task they feel. Teachers who are anxious about trying challenging teaching methods have reduced self-efficacies relevant to those methods and are less likely to take the necessary risks to attempt them. For students, anxiety about learning activities reduces their motivation to attempt them. As experienced teachers know, positive and negative moods for both students and teachers can contribute to self-efficacies and consequently the motivation to meet challenges.

Assessing Self-Efficacy

The quantitative instrument which has been most used for assessing self-efficacy among elementary teachers was developed by Larry Enochs and Iris Riggs' in 1990 and updated by Bleicher (2004). It consists of 23 five-choice questions with two integrated scales; one assesses self-efficacy beliefs for future science teaching activities and the other outcome expectations for those same actions. When used before, during, and after methods courses or professional workshops, relative changes in scores have provided teacher educators with information on change associated with professional development activities. Others have used qualitative assessments of efficacy based on interviews with teachers to judge changes. More recently, to narrowly focus on changes in efficacy beliefs, studies have looked at changes in beliefs associated with specific methods instruction, such as inquiry teaching (Dolin and Evans 2011).

Current Trends

Current work to improve science teaching and learning often focuses on purposefully using a combination of the four ways for developing capacity beliefs to raise teacher and student self-efficacies. Such methods assume that by intentionally focusing on raising these capacity beliefs, students and teachers will be more motivated and successful with science teaching and learning tasks. Most current efforts are aimed at both preservice teachers and experienced teachers participating in professional teacher development. Examples of such elements designed to increase self-efficacies in courses and workshops would include opportunities for teachers to try out new methods of teaching multiple times both with peers and then with groups of students and to get realistic yet supportive feedback each time. Such experiences in relatively controlled circumstances support increases in self-efficacy through **mastery**. Since each participant also gets a turn at teaching their peers, everyone gets to compare themselves with those they feel most alike and therefore through **vicarious** experience are able to raise their self-efficacies. At the same time, instructors as well as all of the teachers in the courses and workshops who witness the teaching episodes give critical yet supportive feedback to one another adding to capacity beliefs through **social persuasion**. Such microteaching experiences in thoughtfully structured circumstances have the potential to reduce **anxiety** and heighten moods as teachers gain specific confidence through incrementally successful experiences.

While this approach to increasing teacher capacity beliefs has shown positive results in motivation and success with science teaching methods, direct connections between the four ways for increasing self-efficacy and actual changes have not been made. Some current effort is aimed at discovering which ways are effective under which circumstances so that future intentional efforts to increase science teacher self-efficacy can be more effectively focused.

There has not been as much formal attention given to increasing student self-efficacy for doing science through conscious use of these four ways, although effective science teachers have long informally employed them for boosting pupil capacity beliefs. However, the implications of general self-efficacy studies are also applicable to managing science student self-efficacies (Pajares and Urdan 2006). Important for students is the expectation of desirable outcomes resulting from science activities. Perhaps more than for teachers, pupils' personal expectations of competence are diminished when they do not expect their efforts to be productive. Teachers can help students overcome this de-motivating effect of low expectations by authentically boosting student self-efficacies through well-structured mastery practice, opportunities for pupils to work with achieving peers, credible and supportive feedback, and attention to emotional barriers to good performance. The rewards are that students with higher self-efficacies are likely to put more effort into their academic work, stay with difficult problems longer, have more positive attitudes, and, in the end, achieve more.

Cross-References

- ▶ Affect in Learning Science
- ▶ Attitudes to Science and to Learning Science
- ▶ Cooperative Learning
- ▶ Emotion and the Teaching and Learning of Science
- ▶ Mindfulness and Science Education

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Self-Study of Teacher Education Practices (S-STEP)

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Keywords

Practitioner research; Reflective practice; Self-study

Background

Self-study of teaching and teacher education practices, abbreviated as S-STEP, or self-study, is a genre of educational research concerned with examining and improving the relationship between teaching and learning in teacher education contexts. In self-study, the teacher educator him/herself is both the researcher and the main focus of the study. Self-study is concerned with the acquisition and development of teacher educators' knowledge of practice and how such knowledge can inform and enhance learning and teaching about teaching. The process of knowledge development in self-study is initiated through the teacher educator's capacity and willingness to publicly problematize his/her taken for granted beliefs and practices about teaching and learning; to be open to, and act upon, the curiosities, surprises, and challenges of everyday teaching practice; and to actively seek out alternative perspectives on practice.

The knowledge produced through self-study is intended both as a means of reframing the teacher educator's personal understandings of practice and stimulating the development of knowledge of practice among the community of teacher educators more broadly. An important function of self-study has been to promote the idea of teaching as a discipline and teacher educators' professional knowledge as specialized and unique.

Historical Roots

Self-study emerged as an organized field of research in the 1990s and was formalized with the founding of the Self-Study of Teaching and Teacher Education Practices (S-STEP) Special Interest Group (SIG) of the American Educational Research Association (AERA) in 1993. Since that time, self-study has acquired a scholarly and organizational presence in the international teacher education community and is recognized as a bona fide genre of research and topic of interest in teacher education practice and research. Consolidation of the field is evident through the production of an International Handbook (Loughran et al. 2004); a peer-reviewed, international journal, *Studying Teacher Education*; and a biennial conference, *The International Conference on Self-Study of Teacher Education Practices*.

Self-study is a qualitative research methodology that shares similarities with practitioner research, action research, and reflective practice. While the distinctions among these forms of research may be blurred, its explicit inclusion of "self" as the focus of study distinguishes self-study from other forms of qualitative research. Self-study researchers draw on a range of strategies in developing, conducting, analyzing, and representing their work. Mostly, these are typical of data-gathering approaches used in qualitative research. Important to self-study is that the researcher carefully selects a range of approaches to data gathering that offer multiple and alternative perspectives on practice. LaBoskey (2004) identified five key elements of self-study: it is self-initiated and focused, is improvement-aimed, is interactive, uses many strategies, and defines validity as a process based on trustworthiness.

Self-Study and Subject Matter

Self-studies are conducted by teacher educators in a broad range of topic areas, contexts, and locations, with many examples readily available in the literature. Typical themes of self-study research by teacher educators include the transition experiences of newly appointed, university-based teacher educators; studies of the implementation of particular philosophies in teacher education programs and courses; the development of subject-specific knowledge for teaching teachers; teacher educators articulating their pedagogy of teacher education; and teacher educators' efforts to address social issues of race, class, and gender.

Self-study has not typically tended to be based around any particular subject/content field. Rather, it has been the teacher education context that has been important. However, in recent times researchers in some areas have published their studies (see, e.g., social sciences (Crowe 2010) and mathematics (Schuck and Pereira 2011) with science education encapsulated in the work of Bullock and Russell (2012)).

Bullock and Russell's *Self-studies of Science Teacher Education Practices* (2012) illustrates how the interaction of science and self-study leads to new understandings of practice similar to those recognized in the science teacher research literature, including recognizing alternative conceptions and learners' prior views, facilitating a constructivist perspective, and confronting technical-rational views of teaching and learning.

Bullock and Russell's edited collection offers insights into teaching and learning about teaching through self-study across the fields of early career teacher educator practices, elementary/primary science teacher education, secondary science teacher education, and, preservice students' learning about science teaching and learning. Their text illustrates well how "self-study methodology offers one way to move beyond technical rationality toward a more productive understanding of professional knowledge" (p. 1).

Cross-References

- ▶ Pedagogy of Teacher Education
- ▶ Teacher Research

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Semiotic Modes and Science Learning

▶ Multimodal Representations and Science Learning

Sex Education and Science Education

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The Lens of Human Reproduction

School and college science typically examines issues of sexuality through the lens of human reproduction. This immediately tends to assume heterosexuality. Biology is all too often presumed to be a neutral subject so that many biology teachers and lecturers continue to teach it as an unquestioned fact. In particular, differences between females and males are often presented as clear-cut and inevitable, and the study of school biology textbooks shows that they are often sexist and typically ignore lesbian and gay issues (Reiss 1998). For example, they often omit all mention of the clitoris and, when they do refer to it, frequently talk of it in a belittling way as the female's equivalent of a penis. Males are rendered visible, females less so; the female exists by virtue of comparison with the male. When homosexuality is addressed, it is generally portrayed as a sort of second-best option, which the reader may well grow out of. However, closer examination of sex in human biology provides plenty of space for critical reflection and allows for a richer understanding of what it is to be a sexual person.

Emily Martin (1991) has shown that while menstruation is viewed in scientific textbooks as a failure (a successful woman would have got pregnant), sperm maturation is viewed as a wonderful achievement in which countless millions of sperm are manufactured each day. Furthermore, sperm are pictured as active and streamlined, whereas the egg is large and passive, drifting along or waiting. The way the egg is portrayed in science textbooks has been likened to that of the fairy tale *Sleeping Beauty*, in which a dormant, virginal bride awaits a male's magic kiss. However, for well over a decade, biologists have considered the egg and sperm as *active* partners. Just as sperm seek out the egg, so the vagina discriminates between sperm and the egg, seeking out sperm to catch.

Social historical research on sex hormones documents that textbooks and scientific papers give messages that go well beyond what the data indicate. For example, since the 1920s it has been known that each sex contains the "other's" hormone (i.e., males contain estrogen and females testosterone). Nevertheless, school science textbooks often ignore both this fact and the close chemical similarity between estrogen and testosterone. Indeed, school textbooks more in line with the scientific evidence about the working of sex hormones would present femaleness and maleness on a continuum (a model common among academic endocrinologists since the 1940s).

The Impact of Faith Groups

School sex education is frequently a contested area for members of faith groups (Halstead and Reiss 2003). Generalizations are difficult because of the variations that occur both within and between religions. Consider, for example, Islam. A core belief of this religion is that God created sexual duality – i.e., male and female – in creation. In both men and women, there is therefore a natural desire for companionship with the other sex. Accordingly, celibacy is not praised. Rather, sexual union gives a foretaste of the joys of paradise, and sexual relations are recognized as one of the great signs of the blessings Allah has bestowed on humankind. While there is a gay and lesbian Muslim movement, there is overwhelming support in Islam for the teaching that homosexuality is unnatural and abhorrent. Muslims feel uncomfortable about sex education conducted within a secular framework, and there are three main aspects of much contemporary practice in Western school sex education that give rise to Muslim opposition:

- Some sex education materials offend against the Islamic principle of decency and modesty.
- Sex education tends to present certain behaviors as acceptable which Muslims consider sinful.
- Sex education is often perceived as undermining the Islamic concept of family life.

Christian views about sex, as about virtually everything, derive from five main sources: the writings of the Bible; the teachings of the Church down the ages; the conscience of individuals informed, they believe, by the Holy Spirit; their God-given, though imperfect, powers of reason; and the particular cultural milieu they inhabit. Marriage has a mystical element to it, the relationship between a married couple reflecting the relationship Christ has with his Church. Indeed, in the Roman Catholic tradition, marriage is one of the sacraments. Christian attitudes to sex before marriage have softened in recent decades. However, homosexuality remains contentious. Some argue that it is clearly prohibited by scripture. Others maintain that both the Old and New Testaments knew little or nothing about mutually faithful adult-to-adult expressions of homosexuality, instead prohibiting cult prostitution and pederasty.

Cross-References

► Biology, Philosophy of
► Social Studies Education and Science Education

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Simulation Environments

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Description

Simulations are a representation of real or hypothesized phenomena used to support learning through illustration of and experimentation with the system. Simulations enact the dynamic processes of a system and often allow the user to manipulate key factors affecting the dynamics in order to explore possibilities, generate hypotheses, or test predictions. Learning with a simulation may be centered around understanding the rules and assumptions that guide the simulation's dynamics or manipulating variables that normally may not be accessible (National Research Council 2011). For example, an interactive simulation of Newtonian physics may allow users to explore and develop theories about mechanics by applying impulse forces to objects and observing the results (diSessa 1982; Clark et al. 2011).

Simulations are typically open-ended with no set directives or roles other than those generated by the user or context of use. In contrast, games and other pedagogies may incorporate a simulation as a part of the learning experience but add an explicit roles or goals that shape interaction. Learning experiences with simulations include (a) using simulations by testing out a variety of scenarios to discover the rules that drive an extant simulation and (b) constructing simulations by studying already occurring phenomena and abstracting/reproducing key concepts in order to virtually reproduce them. The process of simulation construction is often iterative, with learners generating and testing different theories in order to reproduce observed behaviors.

Cross-References

▶ Microworlds

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Single-Sex Classes in Science

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Keywords

Science

Single-sex classes have been introduced into coeducational schools – and in some cases universities – in numerous countries, including Australia, England, New Zealand, Sweden, and the USA. Although a few coeducational schools have implemented single-sex classes throughout the whole school and across all curriculum areas, in most cases they are introduced in specific subject areas and/or for particular age groups. Often, they are introduced with an aim of fostering engagement of girls in "masculine" curriculum areas (e.g., math) or boys in "feminine" curriculum areas (e.g., languages).

Concerns about the underrepresentation of women, compared to men, in science, technology, engineering, and math (STEM) frequently underpin initiatives to teach these subjects in single-sex classes. Arguments for single-sex classes vary. Some argue that there are innate differences between boys and girls that means they learn differently and, therefore, need to be taught differently. However, there is very little evidence to support this argument. Furthermore, such views ignore evidence which suggests that variations within groups of girls and boys are as significant as those between them. On the basis of the available evidence, many scholars reject the notion that there are innate sex differences in learning styles. However, some of these scholars still see benefits in single-sex classes, but for reasons based on social, rather than biological, factors. In relation to STEM subjects, such social arguments tend to acknowledge the effects of long-standing associations between STEM subjects and masculinity, which can have implications for how girls identify, or not, with STEM subjects and also how girls are treated in classrooms. For example, research has suggested that in mixed-sex science classrooms, girls are often marginalized and sometimes sexually harassed; boys dominate the space and equipment; and girls' confidence is frequently undermined. By contrast, single-sex science classes tend to provide more supportive climates for girls in which they build confidence and realize that girls can do science.

Are Single-Sex Science Classes Beneficial?

Researchers have attempted to measure the effectiveness of single-sex science classes in relation to various criteria, including academic attainment; pupil self-concept levels; continuation of the subject beyond compulsory level; confidence; and attitudes toward, and enjoyment of, the subject. Taken as a whole, the findings are mixed, although the weight of evidence suggests that single-sex classes may be beneficial for girls in some ways, for example, in increasing confidence. Reasons for generally inconclusive findings include that many single-sex initiatives are short-lived and often the schools are not clear about the precise purpose of them. Also, schools often implement single-sex classes alongside other schemes or changes, so it is difficult or impossible to disentangle the effects of these. In general, the ways in which single-sex classes are introduced and executed are important determinants of their success; the commitment and support of staff, students, and parents to such initiatives are particularly important.

Criticisms of single-sex science classes frequently relate to how they are taught. For example, there has been important and sustained criticism of programs that treat girls and boys as homogeneous groups and that reinforce pernicious gender stereotypes by tailoring the curriculum in gender-specific ways. Similarly, male classroom teachers who encourage male bonding in all-boys' groups by fostering sexist, macho, or "laddish" attitudes and behaviors have been criticized strongly by pro-feminist and feminist researchers.

Overall, evidence about the benefits of single-sex science classes is mixed. To maximize the potential benefits of such schemes, it is important to be clear about the precise purposes; to ensure staff, students, and parents are well informed and committed; and to implement them in ways that challenge, rather than reinforce, gender stereotypes.

Cross-References

- ▶ Gender
- ▶ Gender-Inclusive Practices

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Situated Learning

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Keywords

Cognitive apprenticeship; Situated cognition; Situated learning; Transfer of learning

A Situated View on Learning and Cognition

The traditional view of schooling treats knowledge as an independent entity, consisting of abstract, decontextualized formal concepts, which should be transferred from an external source to the learner. A problem with teaching practices based on this view is that they often lead to isolated and inert knowledge. Knowledge domains acquired through traditional schooling are often learned and stored in memory isolated from each other and therefore difficult to access. Inertness of knowledge refers to the problem that students are not well capable of using the knowledge they have acquired to solve problems in practice.

The key idea of situated learning is that knowledge and cognition cannot be separated from the situations in which they are learned and used. The notion of authentic activity plays a key role in this view of learning and cognition. The activities through which people develop knowledge are an integral part of the knowledge itself. Understanding is developed through continued use of concepts in authentic situations. The meaning of concepts evolves through this repeated use and is dependent on the way the concepts are used in a particular culture. Concepts are like tools: the use of them is not self-evident but defined by the way the tools are used in a particular community of practice. In this situated view, learning must involve activities, concepts, and culture, as these three are interdependent. Learning is seen as a process of enculturation in socially organized practices, through which knowledge, understanding, and practices are developed. A student must enter a community of practice and its culture to be able to learn to use the (conceptual) tools in the same manner as the members of that community use them. To learn to think like a practitioner (e.g., a mathematician, chemist, biologist), a student must learn to use the conceptual tools in authentic practice. Students need to be able to use a domain's conceptual tools in authentic activity and to be able to observe teachers who, as experts in the domain, are using those conceptual tools in trying to solve authentic problems in the domain.

Situated Learning and Transfer of Learning

In the situated view of learning, students should learn cognitive tools embedded in the situations in which they are acquired and used. Consequently, the knowledge is bound to those situations. However, in education we often want students to learn to also use their knowledge in situations beyond those in which the knowledge was acquired. Therefore, a tension may exist between the desirability of situated learning and the transfer value of the cognitive tools that students learn. Transfer value presumes that thinking strategies are not exclusively bound to those situations in which they were learned, but that they can also be applied in novel situations and on novel problems. Two types of transfer are low-road and high-road transfer. Low-road transfer is achieved through continuous practicing of strategies, in a variety of situations, until they are automatized. High-road transfer is achieved through deliberate abstraction and decontextualization of strategies. These two forms of transfer have strong similarities with the ideas of "near" and "far" transfer that were used in many science learning studies in the 1970s.

Transfer rarely occurs spontaneously. Learners should explicitly be pointed to similarities between the situations in which knowledge was acquired and other novel situations or domains. The best way to achieve both situated learning and transfer does not seem to be to create a kind of compromise between the two, but to emphasize both actively and alternately.

A Cognitive Apprenticeship View of Teaching

The view that all learning is situated in nature leads to a view of teaching as enabling cognitive apprenticeship. A famous ethnographic study by Jane Lave among African tailors showed very vividly how new apprentices started to learn becoming tailors by participating in the periphery of a community of practitioners. Gradually, as they gained experience with the craft of tailoring, they moved from the periphery to the center of the community. In a similar way, in cognitive apprenticeship students are enculturated into cognitive authentic practices.

Learning is viewed as developing a way of thinking and acting that characterizes the culture of a community of practice. In this type of learning, knowledge is continuously connected to the thinking activities which construct, modify, and use this knowledge to interpret situations in that domain and to act in those situations. In this way teaching and learning of conceptual tools (knowledge, cognitive skills) is integrated with the learning and teaching of the subject domain. Domain knowledge ("knowing what") and strategic knowledge ("knowing how") are taught in continuous coherence. The role of the teacher is one of model, activator, monitor, and evaluator of students' thinking, learning, and problem-solving strategies. Teachers may model these strategies by making overt and explicit knowledge construction and utilization activities that usually stay covert and implicit. Teachers may activate students to use learning and thinking activities that they do not use on their own initiative by means of questions, assignments, etc. When students get more skilled in the use of certain learning and thinking activities (cognitive tools), the role of the teacher may change towards monitoring the use of these strategies in students' self-regulated learning and provide students with feedback on their strategy use. Finally, teachers may want to evaluate the quality of students' strategy use. This paradigm is known as situated modeling, coaching, and fading, an essential element of any apprenticeship model ("scaffolding").

Regarding the regulation of learning, cognitive apprenticeship is characterized by a gradual shift in the task division in the teaching – learning process from the teacher to the learner. First, an explicit control structure is offered to the students, and subsequently this help and support is gradually withdrawn. Simultaneously, students are stimulated to internalize this external regulation of their learning processes, and they are taught the skills needed to do so. Learning to think like a practitioner then means a gradual transfer of control over learning and thinking processes from the teacher to the learners, a gradual shift from external to internal (self) regulation of learning and thinking.

Implications for Science Education

Examples of situated learning and cognitive apprenticeship models in science education are Schoenfeld's teaching of problem solving in mathematics; Freudenthal's realistic mathematics education; context-based approaches in chemistry, physics, and biology education; and problem-based approaches in health and medical science education. In Schoenfeld's approach, students may bring problems to the classroom that teacher and students investigate together in a mathematical way. The teacher and students think aloud and make their mathematical thinking as overt and explicit as possible. In this way, students can witness their teacher's and fellow students' mathematical thinking in authentic practice ("modeling"). In realistic mathematics education, students work on problems that are derived from realistic situations connected to their concrete life experiences. The idea is that students learn mathematics by doing mathematics. The teacher guides the students in "mathematizing" the concrete, realistic problems and going through a process of "guided reinvention" to discover mathematical principles in the problems.

In context-based approaches to chemistry, physics, and biology education, students study authentic situations in society in which science knowledge plays a natural role. They work together on solving a certain problem in a meaningful context, guided by the teacher. Learning is aimed at the continuous connection of important (chemical, physical, biological) concepts to meaningful contexts that students are familiar with from their own experience. In problem-based health and medical science education, for example, the start of the learning process is a problem: a short description of a phenomenon about which students should acquire knowledge. These problems are mostly derived from authentic professional practices. Under the guidance of a tutor, students work together in small groups trying to understand, explain, and solve the problem, during which they develop learning goals for independent study. The knowledge gained from independent study is exchanged between members of the group and used to understand and explain the problem.

Cross-References

▶ Communities of Practice
▶ Metacognition and Science Learning
▶ Problem-Based Learning (PBL)
▶ Scaffolding Learning

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Slowmation

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Keywords

Animation; Multimodal; Representation; Slow animation; Stop-motion animation

A “slowmation” (abbreviated from “slow animation”) is a simplified way for university or school students to design and make a stop-motion animation that is played at 2 frames/s providing a slow-moving image that is narrated to explain a science concept (Hoban 2005). It is an innovative way for students to learn science because they engage with a concept in many different ways when creating a slowmation by (i) reading text/images and making summary notes, (ii) creating a storyboard to plan the explanation, (iii) making or using existing models, (iv) taking digital still photos of models as they are manually moved, and (iv) using technology to integrate different modes that make up the final animation.

The explanation can be enhanced with narration, text, or music and is an engaging way to learn because students conduct research and use their own technology to design a sequence of representations culminating in the slowmation, which is a multimodal digital representation (Hoban et al. 2011). The process is very accessible because students use widely available technology such as a digital still camera, a tripod, and any free movie-making computer software.

Through creating a slowmation, students make a sequence of representations as a *cumulative semiotic progression* and their learning is influenced by their prior knowledge, the affordances of the representations created, and the social interactions involved (Hoban and Nielsen 2013). Free examples, instructions, and resources can be found at www.slowmation.com.

Cross-References

- ▶ Model of Educational Reconstruction
- ▶ Models
- ▶ Multimodal Representations and Science Learning
- ▶ Representations in Science
- ▶ Visualization and the Learning of Science

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Social Epistemology of Science

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Keywords

Context of discovery/justification; Critical thinking; Philosophy of science; Scientism; Sociology of science; Veritism

Broadly speaking, social epistemology is concerned with normative questions surrounding the organization of knowledge, which is presumed to have an inherently social character (Fuller 1988). A natural way to interpret education in this context is as a promoter of democracy in the knowledge system, specifically by divesting innovative research of its originally elite character by including it in a curriculum available to many (Fuller 2009, Chap. 1). Thus, what first surfaced in specialist journals and monographs later appears in a more digestible form in widely used textbooks. Of course, if by "science" we mean the natural sciences, the relevant translations may require considerable effort. In any case, pedagogy is more than a simplified version of the research process. Rather, its challenge is to demonstrate an easier way to understand an important scientific finding than simply retracing the steps by which it was originally made. Thus, William Whewell (discussed below) distinguished what we now call the "context of discovery" and the "context of justification," the latter understood as the more efficient ex post facto way of reproducing the former. However, the relevant sense of "efficiency" is not merely a reduction in the number of steps needed to grasp the discovery but also an extension of the discovery's significance beyond the intellectual horizons of the original discoverer.

Positions in the social epistemology of science education may be understood in terms of the prospects of realizing this sense of efficiency. Pessimists generally believe that the most we can achieve is the reproduction of elite knowledge in relatively small groups through specialist science education, to which the rest of the population then learns to defer. This has been the path increasingly pursued by "analytic social epistemology," as discussed in the second part of this entry. However, the first part deals with the more generally – though not completely – optimistic approach to the task that has been undertaken in the history of the philosophy of science.

Philosophies of Science as Social Epistemologies of Education

Much of the philosophy of science has been informed, if not outright motivated, by science education concerns, ranging from the university to the school. The eminent natural theologian William Whewell, who coined "scientist" in the 1830s to describe a specialized profession, lobbied to include natural science instruction in Cambridge to enable students to understand the epistemic bases for the ongoing Industrial Revolution (Fuller 2000, Chap. 1). In practice this meant an appreciation of the method of hypothesis and the explanatory power of general theories. In a rather more democratic spirit, Ernst Mach campaigned at the end of the nineteenth century for using the applied arts and other forms of folk knowledge as platforms for formal scientific training in the secondary school curriculum (Chap. 2). He located the value of science more in its contributions to an individual's cognitive economy than in any high-order form of knowledge it might produce. This put Mach at odds with the professional physics community of his day, which stressed the worldview-building (*Weltbild*) character of the discipline. Nevertheless, his perspective proved influential on the logical positivist movement, several of whose members had come to be exiled from physics to philosophy for taking an unhealthy interest in grounding abstract physical concepts in the most widely accessible forms of reasoning and experience. Popularizations of this sentiment included Percy Bridgman's "operationalism," which influenced quantitative research methods in the social and psychological sciences, and Otto Neurath's universal picture language, "Isotype," which he envisaged as integral to workers' education in the promotion of socialism.

An interesting feature of the dispute between Karl Popper and Thomas Kuhn that would come to define much of the philosophy of science in the 1960s and 1970s is that both were involved in science education: Popper had taken a doctorate in educational psychology and began his academic career as a schoolteacher, while Kuhn's first post, which provided the backdrop to Kuhn (1970), involved teaching the history and philosophy of science to nonscience Harvard majors in a newly established "general education" program. Moreover, Popper's and Kuhn's understandings of scientific inquiry were strongly shaped by the two schools of experimental psychology – Gestalt and behaviorist – that were prominent in the middle third of the twentieth century. This led them to stress the broadly "constructed" character of scientific knowledge. But whereas Kuhn understood matters from the standpoint of those who inhabit the construction (i.e., the psychological subjects), Popper saw it from that of the construction's architect (i.e., the psychological experimenter). This led Kuhn to emphasize the relative difficulty and Popper the relative ease with which scientists can change their cognitive orientation. For Kuhn, science education instills a deep, perhaps even inviolable, commitment, while for Popper it provides no more than a convention whose value rests entirely on its consequences for inquiry (Fuller 2000, Chap. 6). Perhaps the most interesting twist that has been given to the constructionist approach by recent sociology of science has been Collins and Evans (2007), whose concept of "interactional expertise" is meant to capture how people not formally trained in a given science might learn enough simply by interacting with the relevant scientists to end up contributing productively to their work. It remains an open question whether this concept is better understood as an elaborate attempt for sociologists to gain the respect of scientists or an updated version of the project to democratize scientific knowledge originally championed by Mach.

Analytic Social Epistemology and the Socialization of Scientism

"Analytic social epistemology" refers to how social epistemology is practiced by the dominant school of contemporary academic philosophy (Fuller 2007). It has tended to interpret the problem of knowledge in science education as a matter of squaring the demands of truth, critical thinking, and trust in expertise. The juxtaposition of these concerns occurs against a presumed background tension between the norms of science and democracy. However, the relatively insular nature of this literature leads to some idiosyncratic framings of the issues that make it difficult for the tension to be expressed as such. "Truth" is typically understood via the doctrine of *veritism*, according to which a truth-oriented inquiry tracks reliable processes of knowledge production that inquirers may not be able to justify for themselves, in which case they may be rationally compelled to rely on the relevant experts. The question then is how to identify those experts. Depending on the students' cognitive development, they might assess competing arguments or turn to the arguers' track records, assuming that prior relevant cases to the one at hand are easily identified and are not themselves contested. Some of the feminist-inspired literature in this vein speaks of "epistemic injustice," which refers to people whose testimony is not trusted because of who they are rather than what they know (Fricker 1998).

As this brief description suggests, veritism fosters "epistemic paternalism" in the words of its leading proponent (Goldman 1999). Veritism's opponents point to a potential tradeoff between critical thinking and truth seeking: the former is valuable only insofar as it facilitates the latter. Yet, critical thinking is to an "Enlightenment" approach to education that would enable students to exercise intellectual autonomy, especially in response to classroom challenges to their default beliefs. This view, which harks back to John Dewey and entered analytic social epistemology through Israel Scheffler and his student Harvey Siegel (1988), gives pride of place to training the entire person to experience life in an inquiring frame of mind over simply ensuring that the student has acquired an epistemically prescribed set of beliefs (and the means required to access them). In the former case, science is simply a more technically specialized version of general life skills, whereas in the latter, "science" refers to the class of experts to whose judgment one should defer under the relevant conditions.

An interesting consequence of veritism's hold over analytic social epistemology is its transformation of the concept of *scientism*. In its original late nineteenth-century incarnation, scientism was a rather diffuse movement inspired by Auguste Comte's attempt to turn modern science into a new "world religion," one modeled on Christendom that would penetrate every aspect of people's lives while providing a universal basis for social cohesion. Although Comte called his movement "positivism," one might also include Marx's dialectical materialism in this development (Frank 1949). However, the most self-consciously active form of scientism was *monism*, whose German standard-bearers, the embryologist Ernst Haeckel and the chemist Wilhelm Ostwald, set precedents for promoting science as a total worldview in the twentieth century – Haeckel on Darwinian evolution and Ostwald on thermodynamics (aka "energeticism"). In each case, some sense that spirit "emerges" from a material complex meant that science could absorb rather than simply annihilate religion. In that sense, contra Max Weber, science could "re-enchant the world," so that, say, eugenics or energy efficiency might serve as the personal ethics corresponding to general scientific principles (Fuller 2006, Chap. 5). While the dawn of the twenty-first century appears to have reinvented this line of thought in, say, Richard Dawkins and James Lovelock, the doctrine that is nowadays both defended and attacked under the rubric of "scientism" does *not* normally refer to it. Rather, in the paternalistic spirit of veritism, "scientism" nowadays refers much more simply to deference to whatever "scientific consensus" obtains on policy-specific issues. In other words, for the analytic social epistemologist, science aims to replace not religious belief but democratic decision-making (Ladyman et al. 2007).

Cross-References

- ▶ Epistemology
- ▶ History of Science
- ▶ Science Studies
- ▶ Sociology of Science

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Social Networking

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Keywords

Facebook; Social media

Introduction

Technological advancements have contributed increasingly to young people's adoption of social media, a term often used interchangeably with Web 2.0 to refer to online applications which promote users, their interconnections, and user-generated content.

Social networking sites like Facebook and LinkedIn are a form of social media widely adopted among adolescents and college-age youth as a dominant technology-mediated leisure-time activity. Social networking sites are defined by the following socio-technical features: (1) uniquely identifiable profiles that consist of user-supplied content and/or system-provided data, (2) (semi) public display of connections that can be traversed by others, and (3) features that allow users to consume, produce, and/or interact with user-generated content provided by their connections on the site. Social networking sites are distinguished from other forms of social media, like wikis, by the emphasis they place on personal profiling features and interactions with other users' profiles and their shared content (e.g., text, hyperlinks, videos).

Social networking sites are used predominantly to connect with those one already knows and less for traditional networking purposes, but sites such as LinkedIn are designed explicitly for building one's list of personal contacts. Thus, social networking sites are Web-based services through which individuals can maintain existing ties and develop new social ties with people outside their network.

Social Networking in Education

Social networking can be integrated into educational practices in elementary and secondary school classrooms, higher education, and informal learning settings. Research on the use of social networking sites in education has focused on its use by students, especially college students, within a particular course, but less on uses for informal learning. Young people use social networking sites for a wide range of purposes, some of which are educational in nature. Learners can make use of their existing online socializing practices, leveraging their social networks for learning functions in direct and indirect support of education-related tasks and values. These social learning functions can include (1) obtaining recognition for and appreciation of creative work through feedback on their profile pages and (2) reaching out to former classmates to give or receive help in managing the ups and downs of high school or college life or even direct help with school-related tasks (Greenhow and Robelia 2009). Selwyn (2009) describes how students' education-related uses of the social networking site Facebook also included post hoc critiquing of learning experiences and events, exchange of logistical or factual information about teaching and assessment requirements, and instances of supplication and moral support concerning assessment or learning.

Clearly, the application of social networking for educational purposes poses some challenges. Kirschner and Karpinski (2010), for instance, found a negative relationship between time spent on Facebook and college grades. More recent research suggests that the manner in which social networking is used makes a difference in whether academic outcomes are positive or negative (e.g., Junco 2012). For example, posting status updates and chatting on Facebook were negatively predictive of GPA, while sharing links were positively predictive. Interacting with fellow students around curricular content or other learning-related topics may be expected to be positively associated with achievement but also with one's engagement in a practice- or interest-driven learning community.

Science Education

At the time of this writing, there are few published empirical studies on the use of social networking in science education. However, social networking in education generally can facilitate new forms of collaborative knowledge construction, communication, identity work, social capital, and civic participation, both online and offline. For instance, social networking can stimulate social benefits, online and offline, which can have implications for education. Social capital refers to resources or benefits available to people through their social interactions and is valuable to feelings of trust, reciprocity, and social cohesion. Researchers have found positive associations between students' use of their dominant social networking site (e.g., Facebook or MySpace) and both bonding and bridging social capital (Greenhow and Burton 2011). Students have reported that social networking is often part of their learning and high school-to-college transition strategy (Greenhow and Robelia 2009a, b).

Social networking can also enable innovative forms of peer collaboration (Zhang et al. 2009). In studying elementary school students within a formal classroom setting, Zhang et al. (2009) found that social networks within Knowledge Forum provided opportunities for students to connect to a broader network of peers and their ideas than they might have otherwise. This facilitated collective responsibility for the learning of the group and dynamic knowledge advancement over time through flexible, opportunistic collaborations, which in turn served to increase the possibility of diverse spontaneous inquiries, flexible participation from group members, and transparency. In particular, participants could see ideas taken up and modified by the group, which helped students grasp an overarching vision of the changing status of their community knowledge and the interactions taking place at the community level.

Collaboration and coordination among a range of participants may be facilitated by the following features typically present in social networking sites: (1) a nonhierarchical structure, where learners have ownership of and can contribute to a public or semipublic space; (2) the ability to asynchronously coproduce content; (3) automatic publishing capabilities; (4) the ability to adapt the layout or functionality of the environment; and (5) the ability to enable geographically distributed, opportunistic, flexible, and dynamic social arrangements rather than centralized or fixed arrangements.

Thus, social networking can play a valuable role in increasing the diversity of idea sharing and facilitating the cooperative or collaborative engagement of teachers, students, and others in the learning process. Students can use social media to provide feedback and support to peers and also share work with an audience beyond their teacher. Connections can be made with teachers, peers, or even students at other levels of education, across different physical locations, and outside specified class times and with the wider community.

In science education specifically, social networking applications can serve to increase students' interest in science-related issues. For instance, Greenhow and colleagues designed an educational application within Facebook called Hot Dish to allow users to post climate change news stories and comment on them as well as complete "eco-friendly" civic engagement activities, both online and offline in their local communities. Located as a tab within one's existing Facebook profile, the key features of Hot Dish included the ability to post original story entries; share articles from online sources; browse or read articles; curate, rank, and comment on posted entries; craft a personal profile; showcase users' statistics and contributions; and participate in Action Team challenges both online and offline (e.g., writing a letter to the editor, signing an online petition, volunteering for an environmental organization, recycling). The research team found that peer role modeling on this site motivated pro-environmental behaviors as well as argumentation about socio-scientific issues (Greenhow and Li 2013).

Applications like Hot Dish show that social networking features can facilitate information sharing about science issues, commentary and debate, and the completion of problem-solving challenges, activities that engage users in activism around those issues. Similar to gaming environments, users can earn points for completing offline challenges, which acknowledge individuals for offline behavior (e.g., environmental activism) and motivate others in the online environment to make their own behavioral changes. Similar data-tracking and representational features could be built into future science education environments to foster targeted learning (and teaching) behaviors, role modeling, or civic engagement.

Cross-References

- ▶ Blogs for Learning
- ▶ Knowledge-Building Communities
- ▶ Web 2.0 Resources for Science Education

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Social Studies Education and Science Education

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Keywords

Citizenship; Science literacy; Social action; Social studies; STSE science education

Consider voting on a proposal to build a sewage treatment facility to deal with the sewage currently dropped untreated into a nearby body of water when the costs of construction and maintenance of the facility require an increase in taxes. In order to make an informed decision, voters would need enough science background to understand studies of the risk posed by the sewage to the water ecosystem, a good sense of what constitutes a valid scientific study, and a basic understanding of the potential and limits of the facility engineering and technology. This type of science-related knowledge and understanding is called "science literacy," and since the 1970s achieving the scientific literacy needed for active engagement in such personal and societal decision-making has become a fundamental goal of modern school science curricula. This approach to science was called "STS" (science-technology-society) (Yager 1996) or STSE when it included environmental studies. In the 1980s, the STSE approach was incorporated into the "Science for All" or "Public Understanding of Science" movements; a key feature of these movements was an emphasis on social action in and through science education (Hodson 1988).

However, STSE struggled to gain a foothold in schools, due to a number of complex factors. One was the inability of science to understand what is actually involved in effective political action and the history of social change. For example, to vote on the sewage treatment plant, citizens also need to understand economics, dynamics of local governance, geopolitical issues around locating the facility, and the possibilities for civic engagement. In schools these topics, in various incarnations, are generally the focus and territory of the school subject/curriculum area known as "Social Studies."

Parallel Developments of Science and Social Studies as School Subjects

Social Studies and Science as school curriculum areas each represent amalgams of different fields of study. General science, for example, typically includes physics, chemistry, biology, and Earth science; all fields of study concerned with the natural world. Social Studies includes a range of fields of study in the social sciences, such as history, sociology, geography, and civics, that are aspects of studies of the social world of human societies at various levels, times, and functions.

Social Studies came into being as part of the late nineteenth century humanitarianism movement that, in the early twentieth century, was adopted by progressive educators such as John Dewey. The key goal of the school subject "Social Studies" was the development of students' abilities to engage in social progress though democratic renewal. Dewey recognized that this development would not be effective unless taught in partnership with the skills and understanding achieved through interdisciplinary studies that include science and mathematics.

In the first half of the twentieth century, each school subject was continually challenged as a superficial merging of fields of inquiry that deserved their own subject status if students were to understand the underlying ideas and structure of each discipline. This was particularly true with History but also applied to arguments for an early cleaving of school science into the separate subjects of Biology, Chemistry, and Physics (Goodson 1987). Discussions concerned about what constituted a valid Social Studies or Science Education were further complicated by those advocating separate subjects of study in schools that seems to embody aspects of both Social Studies and Science, such as Geography and, in the second half of the twentieth century, Environmental Studies. The debate over what constitutes a valid study of nature or of society was also affected by the two World Wars that punctuated the history of the twentieth century. In science, the World Wars demonstrated the importance of technological innovation and the need for students to choose careers in science, technology, and engineering, while in Social Studies instruction in ethics and civic responsibility were seen as ways to work toward peace through the education of the next generation.

These complex, generative curriculum discussions were refocused in the industrialized Western world by the launching in 1957 of the first human-made satellite, Sputnik by the former Soviet Union. The effect of this event on science education curriculum reform in North America is well documented. What is less often recognized is that Social Studies as well went through a similar reform process approximately a decade later, becoming what was called the "new Social Studies." While science education moved toward a more technical, facts-based approach to science that emphasized the structures of science disciplines, Social Studies initially moved toward developing interdisciplinary studies that explored the "shared humanity" believed to be part of all social systems. The "new Social Studies" did not fare well as many (including parents, educators, and scholars) insisted on a return of the traditional Social Studies topics of national history, world history, civics, and government. Science curriculum reform initially seemed to be more successful, likely due to massive support by governments and the scientific community. However, by the mid-1970s, it was clear that science education was also in crisis; despite a clear goal of attracting men and women to a career in science, engineering, and technology, the new curricula and associated pedagogies were having the opposite effect.

Science and Social Studies: Interdisciplinary Partners for Social Action

STSE science education was, in part, an effort to redirect science education curriculum reform toward a more socially relevant approach to science education and, hopefully, attract more students to science-related careers. But STSE did not emerge as the major approach to science education in the world. Part of this was due to the development of international testing systems, such as initially TIMSS and then from the beginning of this century PISA, and outcomes-based curriculum development, both of which favor curricula emphasizing scientific content knowledge. In addition the development of a more conservative and economically competitive world, political climate moving into the twenty-first century has had similar impact. A key issue in the lack of adoption of STSE science education was the inability of this approach to science to adequately conceptualize the form, appearance, and direction of social action for students; that aspect of education was assumed to be the responsibility of Social Studies.

The separation of the two subject areas is today more acute and problematic than ever. As human populations continue to expand, citizens increasingly face difficult decisions about issues such as disposal of garbage and sewage, traffic control, homelessness, and continued urbanization. Many of these issues are linked to and affected by broader, global dilemmas humankind collectively faces in the twenty-first century, such as global climate change due to increased use of fossil fuels; trying to find ways to feed, clothe, and employ an increasing human population; the appearance of antibiotic-resistant strains of infectious diseases; and loss of biodiversity – as well as an expanding pollution of sources of freshwater and ocean habitats. As well, discoveries in science and technological innovations, such as the development of non-decomposing plastics, genetic engineering, and humanoid robots demand an increased public debate and involvement in the directions of science, engineering, and technology.

School science education can provide a foundation for students to acquire the literacy to understand the key science of these issues, but remains barren in the expertise to assist student development of effective avenues of social action. Social Studies, with a large repertoire of interdisciplinary understanding of the history of societies and how governments operate, can inform science students about methods of social engagement but is somewhat barren, except perhaps in providing a historical perspective, on the science knowledge needed to fully understand current and future issues arising from science discoveries and technological innovation.

Recent efforts to reconceptualize science education as a merging of science, technology, engineering, and mathematics (STEM) and STSE, and a rise in the discussion of values in science education (Corrigan et al. 2007) as well as what might constitute a “citizen science” education (Roth and Barton 2004) may yet serve to foster a more socially engaged science education while also inviting students to consider careers in science, technology, and engineering. But this reform still needs to form a school subject partnership with Social Studies to make progress toward Dewey’s vision of education as a vehicle of democratic renewal. The development of the Internet and social media in the twenty-first century may prove to be the most important technological innovations in this direction. While some argue that it is too large a challenge for the average citizen to think of their responsibilities outside their immediate social situation and geographical locale, there is emerging evidence that youth with access to social media, news media, and the Internet already see themselves as “citizens of the world.” Their global perspective presents an important and timely opportunity for the education of students as local and global citizens, aware of their civic responsibility and able to engage with their peers and others in a democratic, planetary discourse when dealing with urgent issues that cross borders, such as water pollution, climate change, loss of topsoil, and the continued development of technologies of destruction. As well, we look to this generation for the development of new, hopeful technologies that can feed and clothe the growing population and the scientific discoveries that enable a reengineering of societies toward sustainable practices that benefit all species on the planet. These are demanding expectations and to rise to challenge students need a generative, interdisciplinary education, especially issue-focused partnerships between Science and Social Studies.

Cross-References

- ▶ Context-Led Science Projects
- ▶ Curriculum and Values
- ▶ Dewey and the Learning of Science
- ▶ Ecojustice Pedagogy
- ▶ Environmental Education and Science Education
- ▶ Public Understanding of Science
- ▶ Relevance
- ▶ Science for All
- ▶ Science for Citizenship
- ▶ Science, Technology and Society (STS)
- ▶ Sustainability and Science Education
- ▶ Technology Education and Science Education
- ▶ Values and Western Science Knowledge

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Socio-Cultural Perspectives and Characteristics

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Keywords

Ecological consciousness; Indigenous knowledge systems; Ontological relativism; Sciences of all; Sociocultural; Social constructionism; Worldview

During the closing decades of the twentieth century, science education researchers embraced personal construct theory and explored the many interesting ways in which students develop "misconceptions" of the natural world which differ significantly from the canonical scientific view. Pedagogical strategies were developed to enable teachers to detect and remedy these intuitive ways of making sense of everyday experience or, for most students, of the canonical representations contained in the artificial world of the science textbook. The later arrival of social constructivist theory emphasized the crucial role of negotiation and consensus in making sense collectively of personal experience. This resulted in more discursive learning environments in which students negotiate their developing canonical understandings. Science curricula and pedagogies shaped by constructivism and related theories, such as socially situated cognition, continue to work well in assimilating students into the canonical scientific worldview, which was born in the eighteenth-century Age of Enlightenment and has given rise to today's political imperative of *science for all*.

At the same time, however, a political awakening was taking place among science educators with a strong social conscience and a deepening concern about how science and technology are implicated in global crises, such as climate change, that are threatening the well-being of humanity and the planet's ability to sustain all forms of life. These radicalized researchers shifted their attention away from the dominant psychological focus on cognitive activity and embraced sociologically inspired investigations of the cultural relevance of science curricula to peoples worldwide. Researchers reached into other disciplines – philosophy, linguistics, anthropology, politics, and sociology – and adopted powerful sociocultural perspectives to explore critically the history, philosophy, and culture of science and science education.

Most sociocultural theories are underpinned by the *ontological relativism* of social constructionism (e.g., Berger and Luckmann 1966) which holds that explanations of the world are culturally and historically contingent. In other words, none of our explanations necessarily reveal the essence of "things in themselves”; instead, ideas, concepts, and theories are social constructs which are transformable. This transformative perspective applies to scientific knowledge of both the natural world and the social world. In the latter case, social activists are emboldened to transform seemingly natural attitudes and social actions that they perceive instead as cultural products. The rise of qualitative social science research paradigms – *interpretivism*, *criticalism*, *and postmodernism* – has greatly facilitated these transformative inquiries and interventions.

One of the first notable interventions in science education was conducted by critical feminist researchers who identified gender as a social construct rather than an inevitable result of biology. From this perspective, feminist scholars revealed and contested the implicit masculinist culture of science education, especially its girl-unfriendly representations of science in textbooks. Their research demonstrated how a dominant masculine culture had served as a barrier to girls’ participation and achievement in science and to their subsequent selection of science-related careers. The result of this research has been the development of gender inclusive science curricula and pedagogies; in many countries, girls are now outperforming boys in science and mathematics.

As science educators reached further afield, they encountered a range of sociocultural theorists whose powerful ideas have continued to challenge us to radically rethink the fundamentals of science and science education. The following is a small sample of the best known:

- The German Frankfurt School yielded Jurgen Habermas’ theories of *communicative action* and *knowledge constitutive interests*, which have helped to identify disempowering ideologies embedded in the social fabric of educational policies, science curricula, and pedagogies and have brought a moral/ethical perspective to considerations of what constitutes emancipatory social relationships in the science classroom.
- Notable among the French *poststructuralist* and *postmodern* philosophers are Jacques Derrida, Pierre Bourdieu, Gille Deleuze, and Michel Foucault whose sociocultural theories have fuelled deconstruction of the sociological foundations of education systems and institutions, of which science education is an integral part, revealing otherwise invisible economic, political, historical, and cultural assumptions and identifying whose (human) interests are not being well served.
- From Russia, Aleksei Leontiev’s and Lev Vygotsky’s *culture-historic activity theory* provides a framework for analyzing the dialectical relationship between social activities of individual actors (e.g., teachers, students) and the social structure of the organization in which they are embedded (science classroom, school, society). This social constructionist perspective also focuses on the mediation role of language in constructing meaningful ideas, with implications for the role of the child’s “mother tongue” in the science classroom.
- From the UK, *sociology of scientific knowledge* (*ssk*) *theorists*, especially David Bloor and Harry Collins, have drawn on the work of Thomas Kuhn, cultural anthropologists, and linguists such as Wittgenstein to portray science as “shot though” with social influences and scientific knowledge as socially contingent; good news for cultural relativists who advocate an inclusive “sciences of all” curricular standpoint.
- From various nations at the leading edge of political decolonization movements of the twentieth century, the *postcolonial theorizing* of Paulo Freire, Frantz Fanon, Gayatri Spivak, Edward Said, and Homi Bhabha has fuelled cultural studies researchers’ endeavors to neutralize the dominance of the Western modern worldview in science curricula and research, particularly for minority youth in Western countries and majority youth in recently independent nation states (with a special focus on indigenous people).

Sociocultural perspectives constructed from these sources (and elsewhere) are providing renewed impetus to *worldview* research conducted in the early 1990s by science educators such as Bill Cobern. Contemporary culture studies researchers are documenting indigenous knowledge systems (IKS; also known as traditional ecological knowledge (TEK) and funds of knowledge) embedded in traditional community practices of indigenous peoples worldwide. This research is enriching the fields of ethnoscience/mathematics established mid-twentieth century by researchers such as Ubiratan D'Ambrosio. For some time, culture studies researchers have been considering the thorny question of how to reconcile the tension between Western canonical science and indigenous knowledge in order to include IKS as a legitimate part of standard science curricula; the debate is ongoing. Leading culture studies science education researchers include Glen Aikenhead (Canada), Masakata Ogawa and Ken Kawasaki (Japan), Liz McKinley (New Zealand), M. B.Ogunniyi (South Africa), and Greg Cajete (Mexico).

Research employing sociocultural perspectives is transforming our understanding of science and science education and is enabling us to grasp the moral and ethical need for a *socially responsible* science education that prepares future generations with the knowledge and skills to resolve the legacy of global crises, especially loss of biocultural diversity. Indigenous researchers influenced by sociocultural perspectives are conducting studies of their local communities and designing culturally contextualized science curricula to contribute to young indigenous people embracing modern science while also learning deeply about and respecting their own indigenous knowledge, cultural identities, languages, and community practices (e.g., Aikenhead and Michell 2012; Afonso Nhalevilo 2013). By drawing on cultural traditions that honor the connectedness of people and the natural world, it is believed that indigenous knowledge systems will be a source of authentic *ecological consciousness* that can help to revive our sense of stewardship of the planet.

Dedicated journals such as *Cultural Studies of Science Education* and special issues of journals such as the *International Journal of Science and Mathematics Education* (Abrams et al. 2013) are important means for legitimating and disseminating this innovative research.

Sociocultural perspectives have helped us realize the pressing moral and ethical need to complement our endeavors to deliver *science for all* with well-researched curriculum perspectives on *the sciences of all*.

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- ▶ Socio-Cultural Perspectives on Learning Science
- ▶ Teaching and Sociocultural Perspectives

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Sociocultural Perspectives and Gender

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Keywords

Culture; Science education

A sociocultural perspective of science education infers that there is a dialectical relationship between cultural production and creation. Cultural production involves an actor's agency and engagement with schema. When cultural creation is passive, that is, an actor is not actively engaged with culture. When culture is enacted, actors are dialectically involved at both individual and collective levels with cultural enactment in social fields (Tobin 2012). Within a social field, an actor's identity is a combination of one's own construction of self along with how one is constructed by others. Thus, identity is simultaneously fixed and changing.

Gender is a social category and as such structures any social interactions, including those that constitute schooling and science education. As a social category, gender is constituted on the *structural*, the *symbolic*, and the *individual* levels in society. The *structural level* examines how gender influences the organization of society (Harding 1986), for example, examining the division of labor by gender. In science, there is a consistent pattern of more women working in the biological sciences compared to the physical sciences. The biological sciences are perceived as having stronger connections to humans and other living things compared with the focus in physical sciences on innate objects. The former being more feminine and the latter masculine is one explanation for this gendered pattern. The *symbolic* level of gender uses dichotomies where the oppositional pairs are assigned a feminine and masculine meaning (e.g., nature/culture, emotion/rationality, subjectivity/objectivity) that infers what are appropriate practices for women and men. For example, the symbolic level describes science as rational, difficult, and hard, with disembodied knowledge. Thus, both structurally and symbolically, science is a masculine gender practice. In contrast, teaching, especially children, is described as nurturing and caring, which is symbolically feminine. Gender at the *individual* level is influenced by structural and symbolic levels. However, a person's agency can change or modify one's identity based on gender because the levels exist in a dialectic that can impact and transform *structural* and *symbolic* gender. Participants' gendered identities are differentiated in different cultural fields. And one's gender is a major construct on how others construct our identity (Scantlebury 2012).

Typically, science educators use gender of the individual rather than a social context. And as such, gender is often conceptualized as a dichotomy of girls/women/boys/men with the associated descriptors for feminine and masculine traits. There is a lack of *knowledge about gender* in science education research. Many of the studies do not offer a critique of the "gender" concept but focus on comparing female and male students on variables such as achievement, participation, engagement, and attitudes toward science. Butler (1990) challenged the notion of gender by conceptualizing it as performative, and within this framework the research should focus on the intersections between gender, sex, and sexuality. However, science education research has not embraced that the term "gender" is broader than feminine and masculine nor has the field engaged in a critique of the heteronormative language and practices used in science teaching and curriculum materials (Scantlebury 2012).

Moreover, while it is important to consider how gender impacts at the individual, symbolic, and structural levels, feminist researchers view intersectionality as a critical analytical tool to examine how overlapping social categories such as gender/sex/sexuality, race, social class, language, religion, etc., impact a person's identity and also social categories at the symbolic and structural levels. A crucial aspect of *intersectionality* is to view the interplay between different social categories that are unbounded and intertwined and examines society's power hierarchies and differentials (Lykke 2010). This interplay of gender with other social categories can impact and influence participants' achievements and attitudes in science and science education, science pathways and experiences in education, and informal science experiences.

Calabrese Barton (2008) suggested that science educators could utilize the concepts of intersectionality, counterknowledge, and solidarity to define critical science agency. Counterknowledge foregrounds the knowledge and experiences of those who have lived on society's margins, and solidarity reflects how a collective can become agentic to change social structures (e.g., women's involvement with ecological feminism to improve living conditions for their families). Currently, many science educators use gender as a category when often their analysis is based upon girls/women/boys/men (i.e., biological) differences. In order to understand the increasingly complex social fields within science as culture, we should engage with poststructuralist perspectives on gender.

Cross-References

- ▶ Socio-Cultural Perspectives on Learning Science
- ▶ Teaching and Sociocultural Perspectives

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Socio-Cultural Perspectives on Learning Science

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Keywords

Activity theory; Bakhtin; Contradiction; Culture; Dialectics; Vygotsky

Introduction

Sociocultural is an adjective that tends to be used in the Anglo-Saxon scholarly literature when research refers to and employs a range of concepts that have emerged in the particular domain of social psychology developed in the former USSR. Most fundamentally, the adjective is used to denote an epistemology that – in its original conception – uses society, culture, and history as the defining characteristics of human beings. It is also used to refer to a broad, internally highly differentiated movement with very different interests and approaches. The founder of this social psychology was Lev S. Vygotsky (1896–1934), sometimes referred to as the Mozart of psychology. After his premature death, Vygotsky's collaborators and students continued to elaborate and develop this form of psychology. Recent theoretical approaches in this perspective also include in their intellectual heritage the literary theorist and philosopher Mikhail M. Bakhtin (1895–1975) and his circle (V. N. Vološinov, Medvedev) (Depending on the language into which the works of these scholars are translated, alternative spellings of Vygotsky's Russian name (Rus. Выготский) include Vygotski (Fr., Sp.), Vygotskij (ling., Ital.) and Wygotski (Ger., Pol.); the name Bakhtin (Rus. Бахтин), depending on language, also is spelled Bachtin (Ger., Pol., Ital.), Bakhtine (Fr.), and Bajtín (Sp)). The Anglo-Saxon use of the adjective "sociocultural" actually is the result of an unfortunate, and likely politically motivated, choice to substitute the original Russian (from Vygotsky) and German (from Karl Marx) equivalents of *societal* with the linguistically associated but conceptually different adjective *social*. Together with society, Vygotsky, and his students and followers, emphasized *history* so that a more appropriate rendering adjective, as this occurs in some other languages, would be *societal–historical* (or cultural–historical).

Society as the Determinant Factor of Specifically Human Characteristics

The *societal–historical* perspective is fundamentally grounded in Marx's insight that what is specifically human is based on the societal relations in which an individual has participated.

Thus, Vygotsky chose to explicitly refer to Marx when suggesting that all higher psychological functions first are *societal relations* before being *psychological functions* that can be attributed to an individual. More recent analyses show that these functions operate, for the first time, in a societal relation between people. Thus, the ways in which scientists orient each other to, and come to understand, images at work are the same ways in which infants and toddlers and their mothers employ when they begin to read books. From this perspective, personality is the totality of the societal relations that a person participates in, and is subject and subjected to, at any one point in time. From this perspective, therefore, inequities in science achievements between students from the working and under-classes – including those living in poverty or the homeless – and those growing up in the middle and upper classes become understandable in terms of societal issues. In the latter classes, parents tend to spend more time with their infants, toddlers, and children – reading with them about animals or taking them to zoos and science museums – than those from the former classes, where families often struggle simply to make ends meet and to satisfy their basic needs. Thus, despite the rhetoric that comes with such agendas as *No Child Left Behind* (USA), the existing inequities in a society with respect to scientific understandings reproduce themselves with the different kinds of societal relations that children and youth come to participate in. In the Russian source language of the theory, therefore, as well as in the languages that retain the adjective, the *societal*–historical approach lends itself to critique – highlighted especially by those continuing Vygotsky's tradition, including A. N. Leont'ev, S. L. Rubinstein, and, subsequently, K. Holzkamp and the Berlin Critical Psychology group. The originators of the societal–historical perspectives recognized that psychology fulfills an ideological function and, in so doing, serves interests that tend to be those of the middle (bourgeois) class. The adjective *societal* explicitly makes this critical dimension possible, whereas the adjective *social* does not imply inequalities that derive from societal structure. The alternative adjective works against the ideology of an egalitarian society in which every individual is said to have the same potential and opportunities. This critical dimension of the societal–historical approach continues to be of importance in German-speaking countries and Scandinavia; but it is lost when the adjective is substituted by "social."

Marx's insight that *society* is what determines specifically human characteristics is saliently exemplified in the work with deaf and blind children conducted by Meshcheryakov. This work shows that without interactions with others, these children existed in a vegetative state, without any "innate" intention to explore, as Piaget proposed would be the case, and who did not stand upright let alone walk. These children were not incapable (e.g., genetically/intellectually). They subsequently developed specifically human capacities, including not simply learning to use material tools (like a spoon to feed themselves) but being guided to reflect on (by means of their developing intellectual tools) the material tools as objects in their own right. Some of these children, initially found in a vegetative state, subsequently developed to the point that they became university professors. That is, their explorative intentions were not "natural" and innate but rather developed while participating in intentional activities with others and reflecting on the objects involved in the activity and on the activities as a whole.

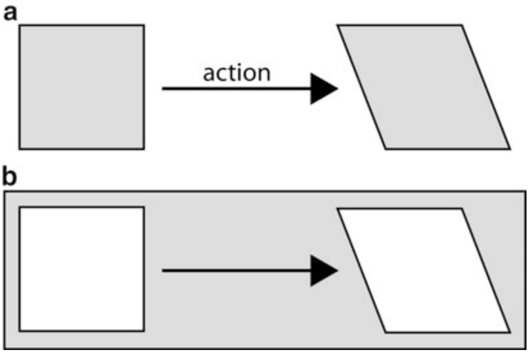
Unit Analysis Replaces Element Analysis

Theoretical Foundation

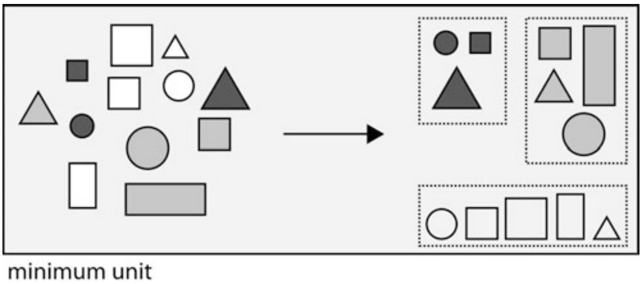
In the societal–historical approach, the unit of analysis shifts from the individual to the collective. Underlying the approach is the attempt to work against the reductionism of cognitivist and biological approaches to exploring learning. Vygotsky suggested that there are two types of analysis used in psychological research: analysis by means of decomposition of a whole into elements, comparable to the analysis of water in terms of the elements oxygen and hydrogen, and holistic analysis, equivalent to the analysis of water as hydrogen oxide. According to Vygotsky, the former is to blame for "all" the failures to understand psychological forms, whereas only the latter is the "correct" starting point for doing a first step in the direction of understanding the human psyche. Vygotsky metaphorically elaborated this contention by saying that to understand why water extinguishes fire, we need to look at the properties of water rather than at the properties of oxygen and hydrogen. When science educators research learning in terms of emotions, or beliefs, or mental frameworks, or conceptions, they reduce the complex human being to elements. This contrasts with the alternative approach that seeks to understand learning in the sciences from the fullness of (everyday) life. In the latter approach, learning in/of science is understood in terms of all the activities in which a person lives in the course of a day, week, month, or year rather than within a particular activity, such as the science classroom. *Perezĭvanie* – which translates broadly as experience and feeling – is one such all-encompassing, irreducible unit that comprises the characteristics of the person, characteristics of the environment, and the temporal unfolding of both.

The following analogy is useful for distinguishing these two approaches, these two forms of analysis (Fig. 1). In this analogy, we model the shearing process that turns a rectangle into a parallelogram. In the common (reductionist) approach, complex phenomena are reduced to elements that are thought to be composing the phenomenon, and these elements are individually considered. Thus, in the example, the element is a square (e.g., representing prior science knowledge). A shearing force external to the square (a cause, e.g., representing an experience) acts upon the shape, changing it into a parallelogram (e.g., postexperience knowledge) (Fig. 1a). That is, there is an observable effect. The parallelogram is another element or, rather, the new shape (form) of a given material entity.

Unit analysis is different; because it is intended to capture change itself, unit analysis requires a minimum unit of *change*. This situation is represented in Fig. 1b. The entire situation including square, parallelogram, change, and time is all part of the minimum unit. In contradistinction to the preceding analysis in terms of elements, all of the square, the dynamic of change, and the parallelogram no longer can be conceived independently. These are taken as different ways in which the unit *manifests* itself. This unit would therefore focus on learning rather than on prior and post-unit knowledge. This also leads to the fact that there are no longer independent causes and effects, a characteristic of all process philosophies from Heraclitus to the present day: A cause is a cause because there is an effect, and there is an effect because there is a cause. This actually captures the observation that in the consideration of processes, we can attribute causes only after having observed something denoted as the effect. In science education research, a teaching method such as the use of analogies might be said to cause higher achievement or conceptual change. Yet in any particular case, a student from an experimental group (using analogies) might achieve less than a student from a control group (not using analogies). That is, whether a science curriculum is a causal force bringing about learning or conceptual change can be decided only after the fact, only after making the observation in any particular case.



Socio-Cultural Perspectives on Learning Science, Fig. 1 Element analysis versus unit analysis. **a** In element analysis the square is the unit, which, subjected to a shearing action (cause), is turned into a parallelogram (effect). **b** In unit analysis, the entire process of change is included in the minimal unit; beginning, end, and everything in between are constitutive parts of the whole



Socio-Cultural Perspectives on Learning Science, Fig. 2 Fundamental to the conceptualization of the socio-cultural approach is that it attempts to grasp change. The minimum unit of analysis therefore has to be one of change rather than one in which elements are subject to external forces

A Practical Example: Classifying

Classifying is one of the core scientific skills. The research literature shows that from as early as 2 years to being a mature scientist, doing science involves classifying objects and events. In the example of the classification of objects typical for a second-grade classroom shown in Fig. 2, the entire activity beginning with the pile of objects until the point of three ordered groups would constitute the minimum unit for a unit analysis approach. This inherently implies all the interactions between students, between students and their teachers, the particular division of labor that was enacted, the forms of participation and the particular rules that were practiced, and the means of production in use. Thus, for example, in the case of leaf classifications, we might consider making available field guides. The societal–historical perspectives then would lead us to anticipate that classifying leaves with and without field guides will change the outcomes. There are studies that exhibit the considerable differences in classification if the field guides employ photographs or drawings, the latter, against expectations, making classification easier than the former. Also, students might create resources for classification, such as a plastic bag with core examples of different categories of leaves. In this case, the activity transforms itself, as new tools are produced and, therefore, change the nature of the activity. As a result, we should expect very different outcomes with the use of technologies. Moreover, from these societal–historical perspectives, we should expect the observed outcomes of activities to change if students are tested in the absence of such tools.

Classification also will be different as a function of culture. This was quite explicit in research that Luria – a founder and leader of what sometimes is referred to as the *Vygotsky circle* – conducted with Kazakh peasants. Asked to sort skeins of wool by color, they refused and suggested this was an impossible task as all the colors differed. According to a Piagetian perspective on human development, these peasants were of lower cognitive capacity than most Western children. However, it turns out that the experience of attending school changed the ways in which these peasants would classify. That is, the cultural and historical (presence or absence of institutional forms of learning) mediates classification and, therefore, the outcomes of the testing activity. We should therefore not be surprised if children growing up in an aboriginal setting with strong focus on cultural heritage – e.g., in Australia, in New Zealand, in Hawaii, or on the Canadian and US Northwest coast – should engage in leaf classification and other science activities related to nature very differently than students in more urban areas and surrounded by more typical Western culture. We should expect that the schooling of science, as well as the schooling of traditional ecological knowledge, would change the ways in which students understand and, therefore, how they would learn and develop with respect to scientific knowledge.

Implications of Unit Analysis

Choosing a minimum unit (category) that is change itself leads to the position that change is the norm (e.g., learning, development) and stasis (knowledge, conceptual framework/structure) is the exception. Whereas in the classical case change (learning, development) is problematic, in the societal–historical approach, stasis is problematic (knowledge, conceptual framework/structure). Every time students engage in and with science, they change – though the nature of the change is not predetermined. For some students, a given science curriculum leads to learning and conceptual change; for others, however, even the best-designed curriculum might turn them away from pursuing a career related to science.

Within this perspective, society – its material and cultural aspects – is understood as a self-moving system. There are no outside (divine or other) forces that bring about the change. In the same way, there are no outside forces that change knowing and understanding. Participation in the activity of schooling, concretely realized in the science classroom, *is* change. There is no being outside of consciousness (knowledge) that makes consciousness develop, in the way that it might appear in constructivist approaches (i.e., a subject constructs its knowledge as if the subject could exist outside of its knowledge). Vygotsky explicitly critiques this latter approach that makes thoughts appear to think themselves.

Vygotsky's coworkers, students, and followers point out that society and its history constitute the relevant unit for thinking about knowing, learning, subjectivity, and personality. The smallest unit, therefore, has to be one that has all the characteristics of society as a whole. This unit, emphasized especially in that perspective referred to as cultural–historical *activity theory*, is an *activity*. Examples of activities include farming, manufacturing, and, pertinent to the present context, *schooling*. To understand what happens in science classrooms, therefore, the smallest unit would be that of schooling (rather than the student, or a group of students, or a teacher, or classroom, or school, and so on). There then exists a whole–part relation between this smallest unit and those aspects in which it manifests itself: school, classroom, teacher, students, curriculum materials, and so forth. Thus, we cannot understand the science student independent of the schooling the student is experiencing: the whole (i.e., schooling) requires students; and to be a student in the way this term is commonly understood requires the societal activity of schooling. Taking only one identifiable part changes the whole and, because of the change in the totality of relations existing within the whole, each part also changes. Drawing on Vygotsky's water analogy, if we take away the hydrogen from water, what remains is a different whole: oxygen. Its behavior and characteristics are very different from the preceding whole, which while it included hydrogen had no behavioral or characteristic similarities with either hydrogen or oxygen. Similarly, if we were to remove all students from schooling, what remains would not be schooling in the way we know it.

In the perspective presented here, material and intellectual tools play an important role. Most tools are used to change the material world. Intellectual tools come in the form of signs, including the various forms of inscription scientists' use and language. These allow humans, as Vygotsky explicitly noted, to control their brains from without. To understand language as a *living* phenomenon, we need precisely such a unit. Thus, language is alive when it changes every time it is used, every time someone articulates a word. A language is dead (classical Latin being one example), no longer changes, when it is not used.

Inner Contradiction

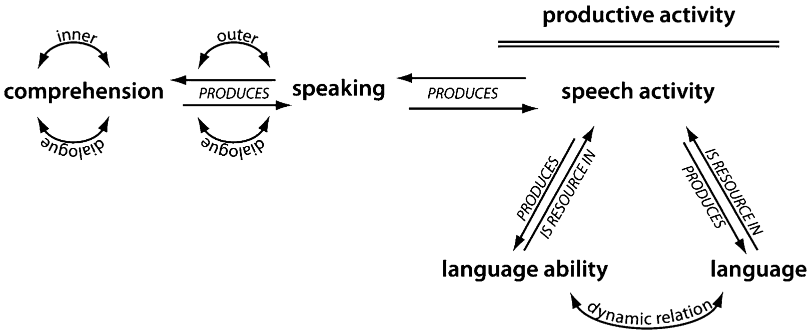
Contradiction is one of the most important categories in the formulation of the societal–cultural perspective on learning. This is immediately apparent when we consider the case depicted in Fig. 2 (and Fig. 1b). We can look at the unit and make one of two observations. These observations differ: the unit manifests itself in one or the other observation. That is, precisely because the minimum unit covers an activity from beginning to its end, we will make differing observations depending on the instant of time when we observe. There is a second way in which observations will differ: these depend also on where we look in the activity. We will make different observations when looking at one (e.g., a child) rather than another individual (another child, the teacher), at the materials (e.g., the after the first few objects being moved), at division of labor (which may change), and so on, even though all of these are part of the same unit (e.g., pereživanie). Classical logic suggests that these differences are the result of looking at different times or at different aspects (people) or the result of different people looking ("interpreting") at a situation. But Vygotsky's dialectical logic, which is based on taking a holistic perspective, suggests that the different manifestations are due to the *inner* difference *within* the unit considered – e.g., in Fig. 1b, the *unit* is a square and a parallelogram simultaneously – rather than *between* elements. Vygotsky explicitly rejects analysis by elements and suggests that only thinking in units will give proper theories of human learning and development.

A second form of *inner* contradiction exists in the fact that in societal–historical approaches, the material (physical) and ideal (mental) are theorized as two sides of the same phenomenon. What happens materially during a science laboratory experiment and the ways in which the events appear in consciousness are two manifestations of the same unit: the activity *as a whole*. Thus, children who classify the shapes in Fig. 2 not only do something materially but also find the material reality reflected in their consciousness and in their affect. Consciousness and affect are understood to be in a dialectical relationship, because each aspect is a manifestation of the current activity. These manifestations are not identical, though they are manifestations of the same (unit). Activities are characterized by their outcomes. Initially, these outcomes exist only on the ideal plane simultaneously with the reflection of the current material state. The participants in the activity orient to these anticipated outcomes. There is then an inner contradiction between the copresent reflection of the present state and the anticipated future state of the activity, the production process.

Dialogue and the Development of Speech and Language

To understand the dynamic nature of language, one has to theorize it as a moving phenomenon. Bakhtin and Vološinov therefore insisted that language changes every time that it is *used*, which always transforms the thing (e.g., Fig. 1b); moreover, they suggest for this reason that the word constitutes the same kind of dialectical unit. With every word or sentence usage, scientific language changes. This then explains how words, such as *atom*, come to be the same and different simultaneously not only from a historical perspective but also from the perspectives of individual development or that of language in a concretely unfolding situation. We can also understand the historically changing ways in the discursive organization of fields, for example, the changes from structure to function in the teaching of biology, or the changing ways in which an individual physics or chemistry teacher might talk about a certain topic from the beginning to the end of her career. The changes are not just changes in individual speech ability but changes in the language at large. Thus, Bakhtin provided a concrete analysis of the changing nature of the novel genre. He suggested that this change could not be understood if we aligned on some trajectory all the forms that the novel has taken historically. To achieve a coherent account, each novel had to be understood instead as a manifestation of current *general* culture and language. The changing nature of language, which occurs because mundane language is changing, leads to the different forms the novel takes. Every change of scientific language is a change in general language, which is the ground upon which any and all scientific languages are built.

Following Vygotsky and Bakhtin, who shared the conviction that dialogue is the origin of language, scholars working from this perspective tend to be very interested in the role of language in science learning. Pertaining to language, its use, comprehension, and development, everything is happening in real, affective–emotive societal relations where concrete speech activity



Socio-Cultural Perspectives on Learning Science, Fig. 3 Model of the relation between the different components in speaking and language

takes place (Fig. 3). Speech activity is subordinated to and constitutive of activity. Activity generates and drives speech activity, which, in turn, generates and drives societally motivated activity: There is a mutually constitutive relation. It is precisely here that we find the word, a phenomenon that integrates interlocutors: speakers and listeners.

Speech activity is concretely realized through speaking and replying, which is based on comprehension, including that of the speaker who comes to know his/her thought (after the fact) in the expressions used. Again, there is a mutually constitutive relation, as speaking concretely realizes speech activity but is produced in the service of the latter. In a conversation, there are interlocutors, who not merely externalize what is their own but who speak *for* the others using language that is not their own but has come to them from the other. Some science educators, therefore, suggest that "misconception" talk is inherently intelligible and shared: science educators understand this talk all the while knowing that it is different from the talk they intend students to use. To properly understand the phenomenon of speaking, it needs to be analyzed from the perspective of hearing, which implies comprehension. Comprehension itself is a dialogical process on the internal plane, and, in fact, all speaking has its genetic origin in *dialogical* speech. Thus, inner dialogue is the psychological reflection of outer dialogue, where it has its origin both at the cultural–historical (phylogenetic) and individual developmental (ontogenetic) levels (Fig. 3). The subjective reality of an *inner voice* is born in its *externalization* for the other. It therefore becomes what it is simultaneously for the other and the individual.

The generative role of speech activity *in societal relations* is shown in the model in Fig. 3 as the arrow from speech activity to language ability, whereby participation in the former is the origin of the latter. At the same time, language ability is a requisite in speech activity: the relation between the two is mutually constitutive. The same mutually constitutive relation exists between everyday speech activity and scientific language. Any change in everyday, scholarly, and aesthetic language emerges in and arises from common speech activity in societal relations, becoming a feature of language as a structured system. Simultaneously, there is always already a language that serves as a resource in scientific speech activity. As a result, we obtain a relation between individual language ability and the language of society. The relation between language as a societal phenomenon and language as a psychological phenomenon is a dynamic relation – and so is that of language as a system and language as a capacity. In terms of the perspective outlined here, speech activity is the category that sublates (overcomes and preserves) and therefore mediates between language as a system and language as a capacity, each of which is a (one-sided) manifestation of the overarching whole.

Thinking and Speaking

In the classical theoretical approaches from Aristotle to Augustine to present-day psychology, speech expresses on the outside what has been thought on the inside and, therefore, what is already represented in the structures of the mind (e.g., conceptions). In the societal–cultural approach, the relationship between speaking (the material dimension of an activity) and thinking (the ideal dimension of an activity) is much more complex. If we consider the situation of an individual student or teacher spontaneously speaking during a science class, then speaking and thinking are taken to be two related *processes*, each contributing to shaping the other, but neither taking precedence. In fact, the two processes are manifestations of one higher order process: *word signification* [Rus. *značenie slovo*] (Vygotsky) or theme [Rus. *tema*] (Vološinov). This overarching process makes it that the same word, even if spoken multiple times in the same unfolding situation, is never the same (never has the same function). Recent studies in science education – as those by Vygotsky and Bakhtin before – show that although there is a stable sound formation, intonation especially, in the articulation of a specific word, the placement of the same sound word changes how it is heard (semantics) and what it achieves (pragmatics). But what a science word achieves in any situation can be known only subsequently. Thus, individual speakers in spontaneous (science lecture) talk will find their thought in what they have actually said rather than expressing what has been thought out in all its details before speaking. Moreover, science education research has shown that language itself is a resource for articulating thoughts even when we have never had these thoughts before. Thus, when asked about some scientific phenomenon – e.g., distance, relative movement, and relative orientation of sun and earth – people respond even if they have never thought about it before. In fact, they may even say they have not thought of this before and still respond to the question. Thus, being familiar with sunrises and sunsets easily allows someone, a child or a Harvard graduate, with rudimentary language competencies to say that the sun moves – it rises in the morning and sets in the evening – rather than that the earth spins around its axis. Because of the everyday experience that the warmth experienced near a heat source changes with the distance to it, it is reasonable for someone to suggest that the earth is closer to sun in summer, especially if one has had no information to the contrary.

From this perspective, the word is not a property of the individual. Any word specifically, and language more generally, is a feature of culture and, by definition, impossible for one person. When a child talks about a phenomenon in a way that some science educators assert constitutes a "misconception," this misconception is enabled by and exists in language. Even if a sound or other sign was to be created and used by a single individual – e.g., Einstein's publication of the special theory of relativity – this would be based on the general practice of communicating by means of signs. Moreover, even when a sound word (science concept) is used for the first time, it implies the understanding of another. This is why other scientists could, for example, understand Priestley when he presented his ideas about "*dephlogisticated* air" (oxygen), even though the adjective had not existed before. Thus, with every sign initially used by one person also comes the possibility of general, shared use. Every idealization inherently implies reproducibility, both by the individual and other persons and, therefore, intersubjectivity.

Intellect and Affect

In the works of Vygotsky, Bakhtin, their students, and their followers, intellect and affect are theorized as two sides of the same coin. They are not independent, somehow *inter*acting elements that determine human behavior, as is conceptualized in most psychological theories. Piaget, for example, described affect as a sort of energy source (gasoline) to a motor (intellect) that does not change the structure of the motor. In the present perspective, on the other hand, intellect and affect are two sides of the same coin: different reflections of the same activity. This holistic conception of activity obviously also leads to the position that affect is not something that can be thought independent of intellect. According to Vygotsky, the separation of affect and intellect is the essential reason why traditional psychological theories fall short of understanding human behavior. This is so because there appears to be an autonomous stream of thoughts thinking ("constructing") themselves irrespective of the interests, motives, and impulses of the *whole* person. As recent research suggests, this means that to understand learning in the science classroom we need to look at the whole person, in the course of leading a life that includes but does not reduce itself to the science classroom. What we observe in the science classroom is a function of its place in a hierarchy of all the daily activities in which the person participates. This, as some studies in this field show, changes what we observe. If teaching physics is fourth in a list of importance for the teacher – following religion, family, and missionary activities – then what happens in and around the physics lessons will differ from observations we might make when teaching physics is the primary activity of the teacher.

From the perspective articulated here, affect and intellect are manifestations of the same activity. Affect is an indication of the difference between the current state of activity and its intended outcome. Being unable to progress through a science activity may be marked by both frustration (affect) and by the understanding that one is stuck (intellect). However, continuing with attempting to progress through the activity may lead to becoming "unstuck," which would be accompanied by more positive affect; on the other hand, not continuing is very unlikely to change the negative affective tone. Thus, even though both teacher and student might be frustrated about how far they are from understanding the task and each other, the only hope for getting closer to achieving their goals is to go on and to engage despite the frustration. Studies show that without this attempt to engage, there is no movement and students and teacher remain frustrated. With engagement, they can hope to get closer to the goal, which in turn tends to be reflected by more positive affect. Of course there is no guarantee that engagement leads to learning and more positive affect; quite the contrary, the parties involved might increase the distance to the intended goals of the science activities or come to understand that there are insurmountable barriers. In both situations, the tonality of affect will tend to be more negative.

Considering affect together with the expansion of action possibilities that emerge from cooperation with others leads us to understand two forms of learning: *expansive* and *defensive*. Expansive learning arises from the fact that in and through our participation, all of our action possibilities, our room to maneuver, and our control over conditions expand. Such expansion is inherently related to more positive affect. This might well explain why students often prefer working in groups. We engage in certain actions even though they may involve hardship when doing so increases our possibilities (e.g., success on an exam) once we are through the hard part (e.g., studying for an exam). Defensive learning denotes the situation where we engage in learning only to avoid sanctions (e.g., receiving a low grade, school suspension). It then becomes completely understandable that some students become perfect cheaters: To avoid low or failing grades, one can become good at a practice that avoids the real goal of the activity, knowing and understanding science, but still achieve the desired outcome (e.g., passing or high grade). When students do not accept the motive of activity, passing or high grade in science, then there is nothing teachers can do to motivate them: the students "don't care anymore." It is quite apparent that this societal–cultural perspective no longer requires us to operate with such concepts as individual motivation.

Learning and Development

One important aspect of the societal–historical approach that is often not well understood pertains to the distinction between learning and development. For Piaget, there existed two different processes, *assimilation*, in which new experience is associated to and understood in terms of existing mental schemas, and *accommodation*, a restructuring of mental schemas to make them appropriate for thinking about experiences that previously could not be understood. The two are very different, independent processes. For Vygotsky, on the other hand, learning and development are related; but learning, he insists, always precedes development. The two are related even though learning refers to a (quantitative) accretion of understanding and development to a qualitative change of understanding that is followed by a fundamental change in the forms of experiences that the person has. To understand this relation requires dialectical thinking, where, as developed by Marx, quantitative change leads to qualitative change. This change from quantitative to qualitative can be observed involving: (a) a particular form of initial understanding (conception); (b) objective changes in the environmental conditions that lead to a contradiction within the person; (c) the emergence of a new form of understanding (conception) existing *side-by-side with* the older type/s of experience; (d) change in dominance from the prior to the new form of understanding (conception); and (e) experiences in terms of the qualitatively new form of understanding (conception). Here, there are two qualitative changes: first, the emergence of a new form of understanding; and, second, the change in the nature of the dominant form of understanding. In this model, the older form of understanding (conception) is not eradicated, as some science educators have previously suggested has to occur in the case of misconceptions, but exists side by side with the older form of understanding (conception). This actually models quite well our everyday understanding that an astronomer can marvel at the beauty of a sun*rise* or sun*set*, a Ptolemean perspective, all the while using a Copernican perspective at work or while teaching astronomy. It has been shown that this societal–historical perspective can be modeled using catastrophe theory, a form of mathematics that combines quantitative and qualitative dimensions to explain the emergence of new forms (e.g., conceptions, talk), that is, morphogenesis.

An important concept that Vygotsky initially introduced to show how learning leads to development is that of the *zone of proximal development*. It was initially defined as the difference between a child's current cultural practices and those that it could enact in collaboration with a teacher or a more competent peer. The latter are said to *scaffold* the individual who is less competent at the task. For example, children in an early childhood science lesson may not arrive at the desired categorization of objects depicted in Fig. 2; they would be considered to be operating at one developmental level. But in the interaction with their teacher, they do achieve the categorization; in this societal context, they are operating at another developmental level. This change then precipitates operating at this more advanced level on their own because with the teacher they already operate at the higher level until they are in a situation to operate at this level on their own (similar to children learning to ride a bicycle by having adults first stabilize the bicycle until they can stabilize it themselves). In contrast to the nature-driven cognitive development in (Piagetian) constructivism, in the societal–historical approach development is mediated by culture.

In this example, the idea of the zone of proximal development is employed asymmetrically: metaphorically the teacher pulls the child to a higher level. However, new research in this perspective has shown that groups of equally capable students achieve *beyond* the developmental levels of any individual in the group. When children engage in the classification of objects such as depicted in Fig. 2, not only the product of activity but also the learning opportunities change if they work alone or in groupings with others, if they interact or not with the teacher. Moreover, recent STEM studies show that in groups with asymmetric experiences, even those to whom more initial knowledge is attributed learn from the group experience. Thus, for example, there are studies in science education showing that not only do science teachers continue to learn to teach while teaching (i.e., pedagogical content knowledge), also they learn and come to better understand the science content. That is, any time people work together in collectivities, that is, when they engage in societal relations with others, we can observe learning and development. Working in and as constitutive parts of collectivities leads to learning by expansion. It is likely for this reason that some scholars, such as Engeström and Holzkamp, have suggested alternative ways of understanding learning that occurs in relations with others. Thus, the zone of proximal development should be thought of in terms of the whole unit of analysis, which changes when a new form of activity is created in the collaboration of two or more individuals (cf. studies on coteaching science or studies on collaborative learning in the science classroom). As a result, there is a distance between current everyday actions and those possible in cooperation with others. In other words, the range of possibilities for individuals and their control over existing conditions increases in the cooperation with others for the purpose of achieving common, general goals; in this cooperation, any individual also increases control over individual conditions. Working with peers and teachers on the classification task (Fig. 2) in the societal activity of schooling not only expands what is collectively achieved but also what the individual can achieve, for example, the affective experiences that come from and with achievement.

Opportunities and Continuing Problems

The societal–historical perspective has proven to be of tremendous use for understanding and planning what happens in science classrooms. Most fundamentally, it shifts our attention from the individual to the collective (the group, class). With this shift, relations to others, language, and the all the material, cultural, and historical dimensions of the setting in which change and learning occur, all come to be made thematic. Despite the tremendous positive impact this perspective has had, there continue to be a range of problems. As science educators reading the works of Vygotsky, Leont'ev, Bakhtin, and other Russian scholars may note, there are sometimes tremendous differences in content and quality between the texts rendered in Russian and their native tongues and the English versions. This will not come as a surprise, as specialist scholars recognize the highly variable quality of translations into some Western languages. Some translations are more exact than others, that is, more in the spirit of the original Russian works. For example, the German and Italian versions of Vygotsky's *Thought and Language* are recognized to better represent what Vygotsky was writing and the spirit underlying his approach. The first English translation of this text omitted many crucial passages, and even the second, somewhat better translation has been criticized for leaving out materials or for incorrectly translating individual words and passages. It has almost completely changed the sense of what Vygotsky has written. The same is the case for the translations of Bakhtin and the members of his circle. Again, the English translations have been labeled as inferior to those that have been produced for other languages. One of the requirements for the continued evolving fruitfulness of the approach therefore would be better translations and a greater attention to the role of society, unit analysis, and the nature of a category (i.e., unit).

Cross-References

- ▶ Acculturation
- ▶ Activity Theory and Science Learning
- ▶ Cognitive Abilities
- ▶ Culture and Science Learning
- ▶ Didactical Situation
- ▶ Discourse in Science Learning
- ▶ Emotion and the Teaching and Learning of Science
- ▶ Indigenous Students
- ▶ Language and Learning
- ▶ Scaffolding Learning
- ▶ Schooling of Science
- ▶ Team Teaching

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Sociology of Science

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Keywords

Anthropology of science; Discourse; History and philosophy of science; Science studies

Sociology of Science and Science Education

Sociology of science offers a number of important contributions to the study of science education. The role of history and philosophy of science is well documented in the development of science curricular materials, but sociology has had a more minor influence in this area. Nonetheless, sociology of science offers an important alternative to the normative views of science often found in applications of philosophy of science to science education. Philosophy of science, particularly from the empiricist tradition, has tended to provide a normative account of theory change, with a focus on the rationality and structure of scientific theories. This has contributed significantly to science education by focusing on the importance experimental work and documenting the value of reasons for theories of conceptual change. History of science has similarly been drawn upon to provide case studies relevant to the development of scientific knowledge for the purposes of teaching concepts and theory change. Sociology of science offers a clear alternative by focusing on the social nature of scientific practices and studying such practices in contemporary settings.

Robert Merton (1973) was instrumental in the development of sociology of science as a field of study. He was concerned, in ways similar to philosophers of the time, with understanding how scientific knowledge was uniquely certifiable. His program of study documented the ways that knowledge in science was certified through social processes adhering to four institutional imperatives: universalism, communism, disinterestedness, and organized skepticism. While these norms were criticized in subsequent developments in the sociology of science, the program of research provided models for the empirical study of scientific practice.

A new sociology of science emerged from the philosophy of Wittgenstein's *Philosophical Investigations* (1958) and Kuhn's (1962) *Structure of Scientific Revolutions*. These sociological studies examined epistemological questions from an empirical point of view. Building on Wittgenstein the scholars sought to understand how meanings were embedded in social practices. These programs of study (e.g., strong programme, empirical programme of relativism) shifted away from the views of philosophy and Mertonian sociology concerned with verifiable and certified knowledge to leave questions about the resolution of controversies and conclusions open to empirical investigations (Kelly et al. 1993). Thus, such studies sought to study the *actual* practices of science through detailed, empirical study, prior to knowing whether a given social group's claims would count as science. This empirical stance and openness provided interesting applications for science education.

Science education has long been interested in promoting goals that include the conceptual knowledge of scientific theories along with knowledge of the nature of science. The sociology of science provides new insights into the inner workings of science and offers the potential to expand the repertoire about what counts as scientific practices in educational settings. Since much of the work of sociology of science has included ethnographic studies of sociocultural practices, discourse analysis of interaction, and institutional analysis, these methodological tools have been viewed as models for investigating the nature of science as it is interactionally accomplished in school science as through detailed, empirical analysis of social interaction. Thus, sociology of science provides ways of expanding what counts as science and ways of investigating science in schools, without specifying detailed normative accounts of scientific theories, practices, or natures.

Applications of sociology of science to science education have led to the empirical study of what counts as knowledge in educational settings. This stance directs attention to examining science-in-the-making as students and teachers seek to construct knowledge and propose ways of understanding through interaction. Such studies draw from educational ethnography and discourse analysis to consider how social practices are constructed, appropriated, and communicated through social interaction over time (Kelly and Chen 1999). Implications of these studies include the needs to consider the social practices that establish knowledge in educational settings. By examining the processes involved in knowledge construction, educational programs can build a more robust view of science and provide potential scientists and non-scientist citizens ways of understanding institutional values and social practices of science. Such examination can demystify the processes leading to scientific knowledge and offer a basis for evaluating the epistemic status of scientific conclusions.

Criticisms of sociology of science as a field are similar to those levied against the application of sociology of science in education. Such criticism focuses on the adherence of seemingly non-epistemic reasons appertaining to the development of knowledge claims. This criticism can be countered by recognizing that reason and rationality are themselves the products of social practices, relying on the social and contextual basis for meaning, institutionalization of norms over time, and the acculturation of members into particular ways of knowing for specific epistemic communities. Nevertheless, sociology of science has demonstrated that the sometimes contentious, agonistic nature of scientific debate that may not be most appropriate for learning science, including even the nature of science. Sociology of science and its implications need to be read and understood from an educational point of view, where considerations of social and cognitive development, pedagogy, and ethics are competing interests with notions of authentic scientific practices.

Increasingly sociology of science and its application in science education have become interdisciplinary. For example, studies from the anthropology and rhetoric science of science have informed both sociology of science and science education. Philosophers are increasingly acknowledging and referring to studies of scientific practices in developing epistemological accounts of science. Thus, the emerging of sociology of science with other empirical studies of science has led to the multi- and interdisciplinary field of science studies, where disciplinary boundaries are less certain or relevant. These science studies are relevant to understanding how scientific practices can be introduced, developed, recognized, and acknowledge in science education settings. The development of interests in environmental sciences, socioscientific issues, and argumentation in science education can be informed on the increasingly detailed, specific, and methodologically inventive science studies.

Cross-References

- ▶ Discourse in Science Learning
- ▶ Empiricism
- ▶ Epistemology
- ▶ Science Studies
- ▶ Socio-Cultural Perspectives on Learning Science

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Socioscientific Issues

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Keywords

Learning; Pedagogy; Research; Scientific literacy; Teaching

Socioscientific issues (SSI) are a conceptual framework used to guide theory, research, and practice in science education with the ultimate aim of fostering scientific literacy. The framework draws on empirical research and scholarship mainly from psychology (developmental learning theory including moral reasoning and cognitive reasoning, character development), sociology (individual and group identity, community, formation of social norms), philosophy (metaethics, normative ethics, virtue ethics), and critical areas of science education that are conducive to the enactment of SSI in curriculum planning and pedagogy. In short, the SSI movement provides a conceptual framework that unifies multiperspectival epistemological orientations of students and considers the role of emotions and character as key components of science education. Used in their ideal form, SSI contain the following main characteristics:

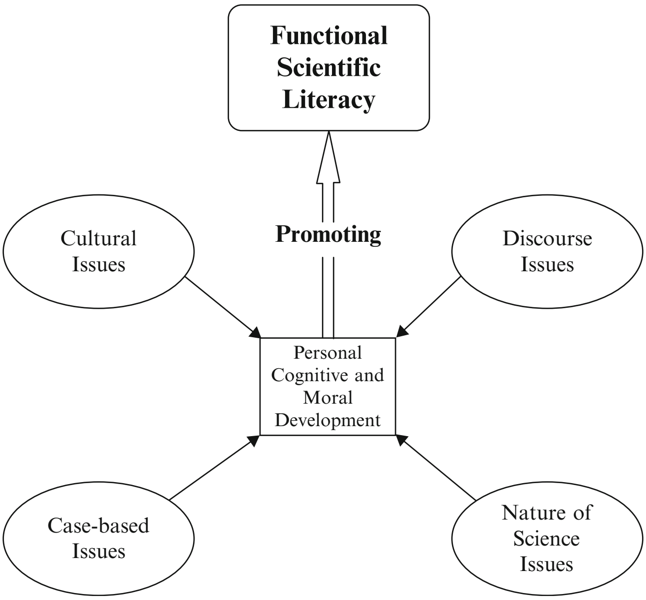
- Controversial and ill-structured problems that require scientific evidence-based reasoning to inform decisions about such topics.
- Deliberate use of scientific topics with social ramifications that require students to engage in dialogue, discussion, debate, and argumentation.
- Tend to have implicit and explicit ethical components and require some degree of moral reasoning.
- Formation of virtue/character as a long-range pedagogical goal is often associated with SSI.

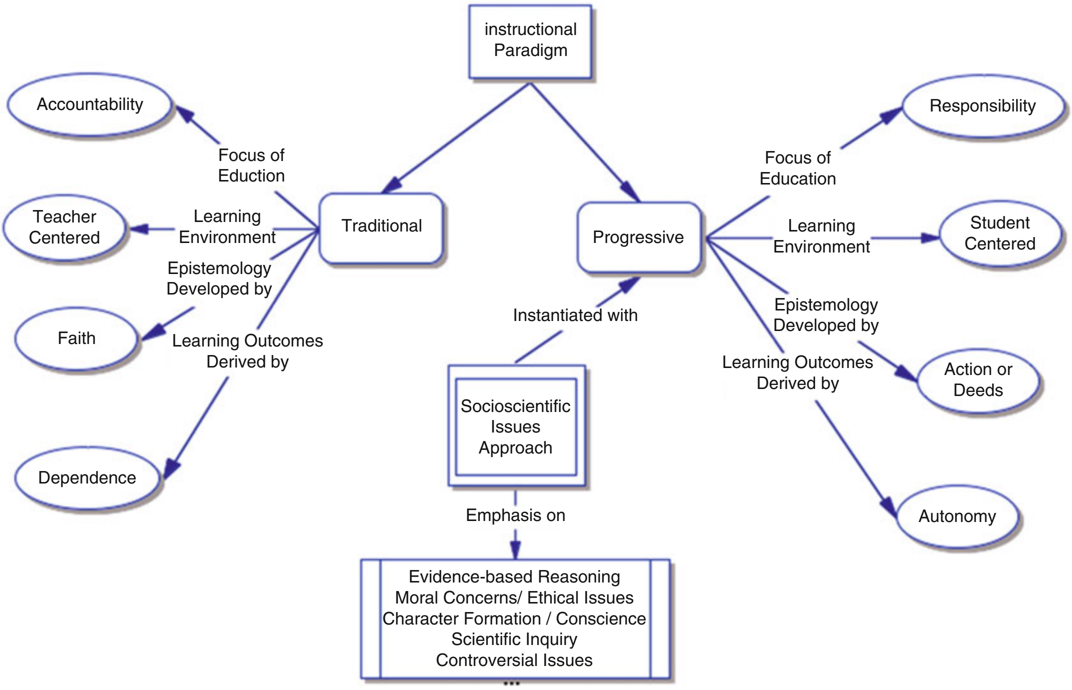
The overarching pedagogical goal is to engage students in the activity of science through exploration, inquiry, questioning, and discourse as they explore issues that are personally relevant to them, as well as relevant to societal and global world views. Deeper conceptual understanding of subject matter becomes necessary to more justly come to resolution of these topics.

Figure 1 depicts a simplified view of key areas of science education, prevalent in the research literature, that are typically tapped to provide a network of understanding while engaging in SSI curriculum development and pedagogy (Zeidler et al. 2005). These areas represent research programs in and of themselves, but can be tapped to help initiate SSI pedagogy. Likewise, there is a reciprocal relationship whereby SSI may help to foster developmental growth in these areas as well. At the center is the nurturing of constructs related to epistemological beliefs that subsume character, morality, rational evidence-based reasoning, emotive reasoning, empathy, caring, and the like – that all contribute to a “functional sense” of scientific literacy. The emphasis on “functional” is important in that it distinguishes between those individuals that may be technocratically competent and those that are ethically astute in the application of judgments that require technical competence – the latter comprising functional intellect and moral inclinations.

SSI are aligned with a progressive view of scientific literacy. Figure 2 contrasts traditional and progressive instructional paradigms and their associated outcomes. Of course, the figure shows extreme endpoints of a teaching continuum and

Socioscientific Issues, Fig. 1 Socioscientific issues framework





Socioscientific Issues, Fig. 2 Pedagogical continuum of learning traditions and outcomes

actual classroom practices may entail movement along different dimensions of the extremes. However, in its purest form, SSI pedagogy stands in contrast to traditional teaching practices and encourages students to prioritize multifaceted factors including interpreting issues, decision-making, solving problems, and engaging in argumentation(Zeidler and Sadler 2008). Certainly, the focus tends to be more on the students rather than the teacher. Attention to these factors is also consistent with ideas that define the "Vision II" orientation to science education found in recent literature.

The term "socioscientific issues" is sometimes written using a hyphen (i.e., socio-scientific issues). While this may be done to appeal to a sense of grammatical style, the use of the terms sans hyphen can also be understood to be quite deliberate. For some, the unassuming hyphen cleaves the social context that such issues entail apart from the science that undergirds them. While it may be suggested that this is an overly academic point, some view the distinction as fundamentally important. The argument is one that views the bifurcation of science into nonnormative components (e.g., data gathering, observation, predictions, scientific methods and processes) and normative components (e.g., prescribing courses of action, choosing to create selected products, decisions about what *ought* to be done) as one that is fraught with peril. While such a distinction is, arguably, conceptually important, it can create a splintered view that allows for the abdication of any sense of responsibility during the practice of science. Some science educators simply do not wish to inadvertently drive a wedge between science proper and the social context in which it resides. That separation is an artificial divorce.

Certainly, SSI can be used as a means to provide a context for argumentation about efficacy of scientific evidence without attention to moral reasoning. Likewise, SSI can be used as a context to develop argumentation skills without attention to the formation of character. Or perhaps SSI may be used as a context to develop more robust understanding of NOS but pay no attention toward an epistemology of human flourishing. This is one reason to choose to use the word "socioscientific issues" rather than the hyphenated version of the term.

The contextualization of scientific content into the problems, experiences, and interests of students' lives is of paramount importance in SSI pedagogy as well as curriculum development. For example, SSI can be used as a forum for the teacher to challenge students' core beliefs about subject matter and conceptual understanding of that discipline. The findings from research suggest that differences in content knowledge are related to variation in the quality of informal reasoning (Sadler and Zeidler 2004). More specifically, students that possess more advanced understandings of scientific knowledge relevant to the issue under scrutiny have greater quality or reasoning on SSI and generally commit fewer instances of fallacious reasoning flaws.

Likewise, SSI can be used as a forum for a teacher to challenge students' normative beliefs related to ethical issues surrounding a given topic. Students are expected to provide justifications for their beliefs related to stances on various topics and challenged to make reasoned judgments about scientific data. Students can also serve as their own facilitators as they discuss, debate, argue, and evoke related forms of discourse to collectively render judgments on vexing normative problems associated with particular issues. These features reflect the kind of sociomoral discourse that is a significant part of the SSI classroom. When students are compelled to consider counterpositions and evaluate evidence or claims from varied sources that may be at odds with one another or dissimilar with their own beliefs, cognitive and moral dissonance is generally created. Dissonance can further be assured when conflicting social norms must be prioritized (e.g., life, affiliation, law, morality and conscience, contract duties, obligation, upholding virtue, social contract, equity, relationships, etc.) thereby creating stronger moral tensions. Dissonance of this nature compels students to negotiate and resolve conflicts and enhances the quality of their own arguments or stances. Using argumentation provides a valuable means to challenge students' critical thinking and reasoning processes, and it mirrors the discourse practices used in real life in the advancement of scientific and intellectual knowledge. Alternative strategies to argumentation and debate include guided discussions led by the teacher and other forms of group inquiry to investigate common claims made in the media or reside in peer groups.

One of the more long-term and "deeper" goals of SSI pedagogy is aimed at the formation of character (Zeidler and Sadler 2008). In contrast to some notions of character education where students are expected to become socialized and compliant to prescribed norms, the development of character under the SSI framework is centered on the formation of conscience. This is accomplished through a process of normation and requires continuous self-reflection and reflexive thinking. It requires the individual to evaluation and scrutinizes their own reasoning and actions and asks how those tasks can be improved. In short, it is akin to seeking the development of conscience and the seeking of virtue in the Aristotelian sense of deeds par excellence. In this sense the development of character requires something more than mere metacognition; it requires the evaluation of actions in terms of their fit with context. This reflects the dual nature of developing conscience. On the one hand, it requires the ability to look forward and anticipate the possible consequences of decisions and consider important factors like long-term consequences, short-term consequences, impact on the physical and social environments, and impact on different stakeholders. On the other hand, it requires the ability to look backward and understand the historical factors that contextualize the boundaries of the issue at hand. This requires the cultivation of a collective social memory and empathy for past historical environmental and social injustices. It is by these processes that the long-range goal of character development is to be realized. Character by way of normation fosters the inclination to want to do what is right and match moral reasoning with moral behavior.

SSI education has been empirically investigated and particular outcomes have been documented in the literature (Zeidler et al. 2009). For example, studies have linked SSI to outcomes that are important both in science education and general education (Zeidler et al. 2011). Examples include outcomes that include (but are not limited to):

- Promoting developmental changes in reflective judgment
- Moving students to more informed views of the nature of science
- Increasing moral sensitivity and empathy
- Increasing conceptual understanding of scientific content
- Increasing students' ability to transfer concepts and scaffold ideas
- Revealing and reconstructing alternative perceptions of science
- Facilitating moral reasoning
- Improving argumentation skills
- Promoting understanding of eco-justice and environmental awareness
- Engaging students' interest in the inquiry of science

More recently, SSI research has been focused on cross-cultural comparisons and research has reflected international partnerships (Zeidler et al. 2013). It has been hypothesized by some that more advanced stages of epistemological reasoning allow individuals to apply a kind of socioscientific reasoning (SSR) akin to scientific habits of mind. SSR is a theoretical construct that entails the ability to tap key traits while negotiating SSI (Zeidler and Sadler 2011). These include skepticism, complexity, multiple perspective, and inquiry. Advanced levels of epistemological reasoning are desirable precisely because those stages allow for the integrated exercise of SSR. It should be noted that indirect evidence exists as well as analytic arguments for the importance and connection of SSR to SSI research and practice. This is certainly an area worthy of future exploration.

Assessment of SSI outcomes for research purposes has clearly been reported in the literature. However, large-scale assessment of SSI curriculum outcomes and instruction is challenging. High-stakes testing like PISA or TIMSS may simply be at odds with the highly contextualized nature of SSI instruction. Outcomes such as epistemological or reflective reasoning, civic engagement, character formation, and the like are simply not conducive to large-scale international assessments. However, there are multiple examples of products for evaluation useful for teachers to consider for their own local classrooms. Such products or artifacts might include:

- Written arguments
  - Poster board presentation
  - Position papers
  - Brochures
  - Letter to the editor (business, school officials, congress, senator, etc.)
- Discussion format
  - Small and large group settings
  - Individual participation within group
  - Debate, report to committee/commission/board
  - Use of effective questioning strategies
- Research efforts
  - Performance of investigative/inquiry research/survey
- Alternative media
  - Power point, video, reenactment, PSA, and video blog

There are numerous ways variant forms of rubrics can be used by teachers to assess the quality of students' evidence-based reasoning as well. Because of the unique nature of each science classroom and the characteristics of students' developmental abilities, the following combinations are left up to the individual teacher:

- Validity of evidence
  - Assertions backed by empirical data

Indicator questions: Validity of evidence – Are student assertions backed by empirical data? Was the correct interpretation of data or use of evidence relevant to position or argument?

- Source of evidence
  - Perceived credentials of study or researcher

Indicator questions: Source of evidence – Has the source of evidence been considered and/or weighted? Have the perceived credentials of study or researcher been examined? Where did the source of the data originate?

- Quality of data
  - Contrasting data based on implied or definitive findings

Indicator questions: Quality of data –Is contrasting data based on implied or definitive research? Have sample size, random versus nonrandom samples, age of data, kind of data, or other data-related issues that play a role in the evaluation of evidence been considered?

- Methodological factors
  - Features and design implications of study

Indicator questions: Methodological factors –Have design features and that have methodological implications of the study been considered?

- Scientific content
  - Interpretation of data in regard to science content

Indicator questions: Scientific content – Is the student's interpretation of the data correct? Have appropriate data in relation to the issue under investigation been selected properly? Have interpretation, weight, and meaning been considered?

The wealth of empirical data reported in the international science education literature supports the position that socioscientific issues are and continue to be a worthwhile use of classroom time that results in valuable pedagogical and developmental outcomes.

Cross-References

▶ Bildung
▶ Science for Citizenship
▶ Science, Technology and Society (STS)
▶ Scientific Language
▶ Scientific Visualizations

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Student Peer Assessment

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Keywords

Peer evaluation; Peer feedback; Peer instruction; Peer judgment; Peer marking

Definition

Peer assessment is a process during which students consider the quality of a peer's work or performance, judge the extent to which it reflects targeted goals or criteria, and make suggestions for revision (Topping 2013). Peer assessment is task specific; the assessment is of the quality of the peer's work, not a student's abilities or personal qualities. The peers can be in the same or different grade, of similar or different ability levels, and can be randomly assigned, teacher assigned, or self-chosen.

Although peer assessment can serve both formative and summative functions, it is important to emphasize the richness of information that comes from formative, non-evaluative peer feedback (Topping 2013). While summative peer assessment, also known *as peer marking* or *peer evaluation*, is usually limited to grading or scoring, formative peer assessment contains qualitative information on the strengths and weaknesses of another student's work as well as suggestions about next steps toward targeted goals and objectives. Therefore, while peer assessment can be used summatively, it is more typically applied in a formative fashion (Bryant and Carless 2010).

Theoretical Framework

Theory and research on peer assessment are grounded in scholarship on feedback, formative assessment, and constructivist learning. A constructivist learning environment that encourages trusting relationships and communication among peers allows for diagnoses of understanding and misconceptions, and honest feedback (Topping 2013). Feedback that is substantive, supportive, and timely can promote learning (Hattie and Timperley 2007). In terms of formative assessment, feedback to learners and teachers involves three main processes: (1) determining, clarifying, and understanding the goals, objectives, and expectations for the task; (2) gathering evidence of and interpreting students' current knowledge and skills through relevant performance tasks; and (3) providing feedback that teachers and students can use to move forward (Wiliam 2010). Under the right conditions, learners can provide useful feedback for each other through interactions between the *assessee* (the peer being assessed) and *assessor* (the peer providing the feedback).

Carefully structured peer assessment helps learners seek answers to three questions that coincide with the process of formative assessment described by Hattie and Timperley (2007) and Wiliam (2010):

1. **Where Am I Going? Goal Setting**
   An understanding of the learning goals for a task is a critical aspect of feedback. As such, one of the major components of peer assessment is the articulation of assessment criteria and expectations, whether through the distribution of rubrics, co-creation of

criteria, or explanation and discussion of expectations and goals (Topping 2013). Interactions between teacher and learners and between assessors and assessees about the criteria and expectations for the task can enhance understanding of where they are going, ensure similar interpretations of the goals by teachers and peers, and promote a shared sense of commitment to attaining them (Hattie and Timperley 2007).

2. **How Am I Going? Progress Monitoring**
   Another important element of assessment is information on the learner's progress toward the targeted goals. Such information can include feedback on the performance relative to the goals and expectations or as compared to prior performance. The use of a structured process of critique is helpful for ensuring constructive peer feedback.
3. **Where to Next? Moving Forward**
   The influence of feedback on learning is based on the learner's decisions about where to go next or what to do to deepen learning and improve performance (Hattie and Timperley 2007). Concrete suggestions for improvement and timely opportunities for revision are essential.

Important Scientific Research and Open Questions

Research in different countries has focused on the academic and social benefits of peer assessment; teacher, parent, and student perceptions of its value; and validity and reliability. Much of the available research has focused on writing and has been done in higher education contexts, although children as young as 9 years of age have been successfully involved in the process of peer assessment (Topping 2013).

Research suggests that there is a positive relationship between achievement and peer assessment, particularly in noncompetitive cultures and when learners are trained in constructive feedback techniques. For example, students who engaged in peer assessment that emphasized strengths, weaknesses, and suggestions for improvement of their writing tended to produce higher-quality final drafts than those who received only teacher feedback (Topping 2009, 2013).

Research has also revealed a relationship between peer assessment and social skills. When teachers create a classroom community where learning targets are clearly defined for students and constructive peer critiques are implemented for the purpose of revision, the frequency and quality of help seeking, help giving, and students' attitudes about asking for help have improved (Topping 2009).

Peer assessment can be beneficial to the assessor as well as to the assessee. Observing and critiquing a peer's work places sophisticated cognitive demands on assessors, including monitoring, detecting, diagnosing, and correcting performance and listening, explaining, questioning, and summarizing a concept. Taken together, these high-level cognitive processes can promote the internalization of knowledge and self-assessment by the assessor (Topping 2013).

Studies of the perceived value of peer assessment indicated individual and cultural differences. For example, teachers and parents of children in primary grades seem to value peer assessment more than the students do. Both primary and secondary school students without training or experience had concerns about this assessment practice, but in a study of students in secondary school, learners acknowledged the ways in which assessment of their peers naturally promoted thinking and reflection on their own progress and performance (Topping 2013). Learners tended to devalue peer assessment in high-stakes educational contexts, competitive classrooms, and when assessment was used for purely summative purposes (Bryant and Carless 2010; Topping 2013).

Research on the reliability and validity of peer assessment or peer marking has examined the degree to which learners' assessment of their peers' work is consistent with their teachers'. The results have been mixed. In instances when peer assessment was found to be inconsistent with teachers' assessment, the quality of training in peer assessment and students' level of involvement in the process were questionable (Topping 2013). In contrast, when learners were taught the appropriate processes, there tended to be surprisingly little difference between peer assessors' and teachers' evaluations. The more elaborated the feedback, however, the more variance there was between the responses of different assessors. In short, when students are trained in the assessment process, reliability is generally at least adequate (Topping 2009).

Although a significant amount of research has shown peer assessment to be a promising instructional tool, more work is needed to understand its implementation and outcomes and to address a concern about the generalizability of the technique across age, culture, and subject areas. Optimal peer feedback procedures should be determined for a variety of contexts in order to ensure high-quality implementation (Topping 2013). Research on peer assessment should expand to more comprehensively examine the elementary and middle school grades as well as language learners and students with disabilities. The role of peer assessment in contexts that stress high-stakes testing should also be examined. Finally, claims that the peer feedback process enhances the self-esteem and social connectedness of children who are socially rejected or disliked (Topping 2013) should be empirically tested.

Cross-References

- ► Formative Assessment
- ► Student Self-Assessment

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Student Self-Assessment

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Keywords

Self-evaluation

Definition

Many terms have been used synonymously with self-assessment, including self-evaluation, self-reflection, self-monitoring, self-rating, self-scoring, self-marking, and self-grading (Andrade and Valtcheva 2009; Brown and Harris 2013; Falchikov and Boud 1989). Broadly, self-assessment refers to an evaluative process during which students assess and provide feedback on their own work. Falchikov and Boud (1989) suggest that self-assessment can serve both formative and summative purposes. From a formative perspective, self-assessment contributes to the learning process by focusing students' attention on areas in need of improvement: Students use their assessments to determine the extent to which they have met designated task criteria or standards and to identify areas of improvement. Serving a summative purpose, teachers can use student self-assessments for grading. Regardless of the purpose of self-assessment, Falchikov and Boud (1989) contend that self-assessment (a) is criterion referenced, meaning that the act of assessment must involve explicitly stated criteria, standards, or expectations, and (b) involves comparisons of one's own work to that set of criteria, standards, or expectations.

Broader and narrower definitions of self-assessment have also been proposed. Taking an expansive stance, Brown and Harris (2013) argue that the act of self-assessment should not be restricted to evaluating work against "socially agreed criteria" (p. 368) because doing so limits the ability to investigate and distinguish between the effects of different types of self-assessment. This broad conception of self-assessment involves students making formative or summative judgments about the characteristics of their work or capability to do work. The judgments may be quantity estimates, such as grading, or quality estimates, such as comparing aspects of one's work to a set of criteria.

Andrade (2010), however, proposes a narrower definition of student self-assessment as a formative, task-specific process during which students first generate feedback on the quality of their work by assessing the extent to which it meets explicitly stated criteria and expectations and then, through a process of revision, use their self-generated feedback to improve the quality of their work and deepen their learning. Andrade emphasizes the formative nature of self-assessment, indicating that self-assessment is done on works in progress in order to inform revision and improvement. According to this definition, a distinction is made between self-assessment and self-evaluation, the latter being a summative process whereby students assign themselves a grade. Andrade warns that summative self-assessment might not promote learning to the same degree as formative self-assessment methods because in summative self-assessment the students' intentions are to produce a desirable yet defensible score rather than to generate useful feedback for revision (Andrade and Valtcheva 2009). Andrade also made a distinction between self-assessment and self-reflection, suggesting that self-reflection is not task-specific, as it calls for students to make judgments about strong or weak abilities for the purpose of engaging in self-discovery and awareness.

Theoretical Background

The major theoretical premise of self-assessment is that it mentally engages students in a process that serves to develop academic self-regulation (Andrade and Valtcheva 2009; Brown and Harris 2013). Students with high self-regulatory skills take ownership over their learning and rely less on teachers to achieve challenging learning goals. The process of evaluating their own work can help students develop skills in regulating their performance and learning, which can lead to deeper, more meaningful learning and ultimately result in higher gains in achievement. Andrade and Valtcheva argue that self-assessment is an important component of self-regulation, indicating that self-assessment makes students aware of the goals of a particular task and prompts them to monitor their own learning by checking their progress in relation to those goals. Similarly, Brown and Harris suggest that engaging in self-evaluative tasks promotes the development of metacognitive competences essential to self-regulation, such as self-observation, self-judgment, self-reaction, task-analysis, self-motivation, and self-control.

Self-assessment can serve self-regulatory purposes by having students describe and generate feedback on their own work. Hattie and Timperley (2007) developed a three-step feedback model: First, focus the feedback on specific learning targets; then, have students consider where their work is in relation to those learning targets; finally, have students articulate what they can do to fill any gaps. To generate feedback using this model, students simply ask themselves: "Where am I going?" "Where am I now?" and "How can I close that gap?" Meta-analyses of feedback suggest that the quality of feedback can have a large effect on achievement, with an average effect size of 0.79 (Hattie and Timperley 2007). Hattie and Timperley suggest that effective forms of feedback contain information on how to improve performance on a specific task. Students generate this type of feedback when engaging in formative, criteria-referenced self-assessment. Formative self-assessment using rubrics, checklists, and journals has been associated with increased sophistication in the quality of students' writing, as well as increased mathematical vocabulary, better performance on word problems, and higher independence in mathematics problem solving.

Several methods of self-assessment have been devised to assist students in generating feedback on their learning. Brown and Harris (2013) state that methods of self-assessment generally ask students to evaluate either quantity or quality aspects of their work. Evaluating quantity aspects of one's work can include using a scoring guide containing correctly scored answers to assign a grade, score, or rank order or to estimate performance on a test or task. Evaluating quality aspects can include using a rubric to compare the quality of one's work or performance against a set of criteria.

In formative self-assessment, rubrics are often used to judge the quality of performance-based tasks such as writing, portfolios, and presentations. A rubric is a "document that lists criteria and describes varying levels of quality, from excellent to poor, for a specific assignment" (Andrade and Valtcheva 2009, p. 13). Rubrics not only support students in evaluating their own work but also serve as a teaching tool: Rubrics set the target for a task, describe both strong and weak work, and warn against the types of mistakes students tend to make on the task being evaluated. Once students have self-assessed their work using a rubric, they can revise it and use the rubric to repeat the process, at least until self-assessment is internalized. In addition to rubrics, Andrade (2010) suggested that checklists, journals, and student interviews can also be used to engage students in formative self-assessment.

Several important conditions should exist in order for students to receive the full learning benefits of self-assessment. Based on Brown and Harris' (2013) broad perspective, the form that self-assessment assumes, whether it is formative or summative, is irrelevant; effective self-assessment involves high mental engagement, is focused on the processes of self-regulation, and is scaffolded by the teacher. According to this view, good self-assessment is guided by the teacher and asks students to compare their performance against objective criteria, such as correct vs. incorrect test answers, or rubric-based criteria. Andrade and Valtcheva (2009) agree that teachers should play an active role in the self-assessment process, suggesting that teachers provide direct instruction on how to engage in self-assessment, give feedback to students on their self-assessment, and teach students how to use self-assessment to improve their work. Andrade (2010) argues that the climate of the classroom is also important to the success of self-assessment: Students need to perceive and understand the value of constructively critiquing their work and trust that their self-assessments will be respected by their teacher.

Andrade (Andrade 2010; Andrade and Valtcheva 2009) indicates several additional conditions for a formative, criteria-referenced approach, including the incorporation of a revision process during which students use their self-assessment feedback to improve the quality of their work or performance. Another characteristic of formative self-assessment is that students' judgments must not involve assigning a grade or score but should instead focus on identifying ways to revise and improve the work to meet the target criteria.

Important Scientific Research and Open Questions

Studies indicate that self-assessment is associated with learning and achievement. In a meta-analysis of 84 empirical studies of both formative and summative forms of self-assessment, Brown and Harris (2013) found a median effect size of between 0.40 and 0.45. This suggests that, on average, students who self-assess their work achieve almost a half standard deviation higher than those students who do not engage in self-assessment. The meta-analysis also suggests that self-assessment is related to gains in learning and achievement when students are (a) trained in self-assessment strategies; (b) provided guidance in self-assessment through models, correct answers, or teacher feedback; and/or (c) involved in the construction of task criteria and expectations. In addition, self-assessment that involved students in monitoring, rewarding, and making predictions about their achievement and accuracy as compared to objective criteria was correlated with gains in achievement.

Research investigating the accuracy of self-assessment has focused on the degree to which student self-assessments agree with teacher assessments. Young students tend to overestimate their performance by rating their work higher than the teacher, whereas older students tend to underestimate their performance and have ratings that correlate more strongly to teacher ratings (Brown and Harris 2013). The self-assessments of high-achieving, proficient students tend to agree more with teacher assessments than do those of low-achieving students. The research suggests that students' self-assessments agree more strongly with teacher assessments when students are taught to self-assess, have task-specific knowledge of the content, and know that their assessments will be compared to peer or teacher assessments. The tendency of students to inflate their self-assessments when they are counted towards a grade serves as a justification for the use of formative approaches to self-assessment (Andrade and Valtcheva 2009; Brown and Harris 2013).

Many questions about self-assessment are worthy of investigation. Although there is some evidence that self-assessment is linked to increases in motivation and self-regulation, the results from studies of this link are inconsistent (Brown and Harris 2013). Therefore, questions remain about the extent to which self-assessment contributes to motivation and the development of skills in self-regulation. Similarly, claims have been made about the effects of self-assessment on metacognition, yet very little research has investigated these effects. Research is needed to determine whether and how ongoing self-assessment experiences result in more and better metacognitive processing.

Little research has explored the relationship between the accuracy of students' self-assessment and gains in achievement. As noted by Brown and Harris (2013) and Andrade (2010), low-achieving students are often inaccurate in their self-assessments, yet they can still make gains in achievement through self-assessment. This raises the question of whether or not self-assessment accuracy matters. If accuracy of self-assessment is found to affect achievement, research should explore the components of the self-assessment process that contribute to improved accuracy in self-assessment.

Cross-References

- ▶ Formative Assessment
- ▶ Metacognition and Science Learning

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Student Teacher as Researcher

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The idea of student teacher as researcher should sit comfortably with the intentions of teacher education and the process of learning to teach. It seems obvious that if student teachers are placed in positions where they can learn to challenge their existing views of practice through researching their own experiences of teaching, then such learning should be both valuable and meaningful in shaping their subsequent practice. Despite the apparent common sense of such a view, there is very little literature to suggest it is the case.

Project START (Student Teachers as Researching Teachers, Cochran-Smith 1991) is one of the few examples of the type of approach briefly noted above. Cochran-Smith described project START as being based on the notion of "collaborative resonance" because it was designed to "Prepare student teachers who know how to learn from teaching by inquiring collaboratively into their own practices and who help build cultures of teaching that support ongoing professional growth and reform" (p. 106).

Obviously, for a student teacher to learn about teaching through a student teacher as researcher stance, then such learning about teaching must be embedded in their experiences of teacher education. Project START did just that through a curriculum structured around opportunities for participants to engage in four kinds of teacher research – oral inquiry processes, essays, journals, and classroom studies – all of which were designed to raise questions and encourage data collection and analysis of particular aspects of learning about teaching. In many ways, project START focused on what Munby and Russell (1994) described as the "authority of experience."

Munby and Russell's research in the authority of experience in learning to teach led to two major student teacher as researcher outcomes as documented by Derek Featherstone (see Featherstone, Munby and Russell, 1997) and Shawn Bullock (see Russell and Bullock, 1999). Both of their accounts of researching their practice illustrated how, through creating situations that encouraged them to recognize and build on the authority of their own experience, their learning about teaching was substantially enhanced.

Featherstone's research clearly illustrated how his views of teaching and learning changed as a consequence of seeking feedback from his students about their learning in his classes. As a consequence of his careful "listening to his students," he found new ways to better construct his teaching in line with his hopes for his students' learning and their feedback on the quality of that learning. One particular aspect of his research was on the teaching of "natural succession" through which the data he collected and the subsequent analysis he conducted highlighted the value of purposeful inquiry into teaching by listening to, and learning from, his students. Featherstone's study showed how a student teacher as researcher stance fundamentally influenced his learning about teaching in very powerful and explicit ways.

Bullock, another student teacher who responded to the authority of his experience, launched into an extended research project in which he spent a considerable period of time documenting and analyzing his practice. As a consequence, he began to see differences between his views of science learning and the actual science teaching he was employing in the classroom. He therefore decided to step out and take risks in his practice and encourage the learning he hoped for rather than be secure in the teaching approach that gave comfort through traditional curriculum delivery. Although as a novice teacher he felt uncomfortable in not directing his students' learning of science in ways he was more familiar with, he soon saw the value in allowing his students to explore science for themselves. His experiences of learning to teach science through researching his practice created insights into teaching that fundamentally shaped his practice. Bullock's student teacher as researcher stance set an approach to learning about teaching that dramatically impacted his future career as he became a thoughtful teacher researcher and later teacher educator (Bullock 2011). In both cases, his grounding in researching his own practice as a student teacher gave him the impetus to do the same in his ongoing career.

In a longitudinal study over 3 years, Loughran (2004) documented his student teachers' research into their own practice. Again, the substantive approach was embedded in their own experiences through which they accepted greater responsibility for directing their own learning about teaching. Loughran encouraged the use of anecdotes as a catalyst for his students to study their practice. That approach served as a way of helping them to recognize the differences between what they were doing and what their students were learning and how they interpreted the gap between purpose and practice. Anecdotes encouraged his student teachers to draw on critical incidents in order to meaningfully reflect on their practice and pursue deeper understandings of the problematic nature of teaching.

His student teachers' projects consistently illustrated how they chose to revisit their own experiences and to begin to reconsider concrete aspects of their teaching that they could do something about. In so doing, they began to see new ways of investigating and interrogating their own learning about teaching and to build knowledge of practice that was informing and useful to them. Many of his student teachers' research studies were not pre-organized as a form of assessment per se, but rather developed as a response to emerging issues in their practice.

For those teacher educators invested in student teacher as researcher, a major hope is that novice teachers come to better understand the value of research in teaching and learning and to highlight how informative and applicable it can be to their classroom practice. Bullock's work is certainly a strong and important example of the value of setting such a foundation to learning to teach and illustrates well how important studying practice is to teachers as a way of improving the learning outcomes for their students.

Cross-References

- ► Self-Study of Teacher Education Practices (S-STEP)
- ► Teacher Professional Development
- ► Teacher Research

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Student Teachers' Needs and Concerns

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Student teachers enter the university training program to become a teacher first of all on the basis of having been a student in school for many years. Their a priori concepts about being a teacher and their beliefs about teaching and learning are mainly based on their experiences collected while having been high school students and by being a learner at university. Because many teaching practices in high schools all over the world, and also in universities, especially in chemistry and physics education, are not necessarily in line with educational theory, e.g., in terms of a student-centeredness and a constructivist approach to teaching and learning, the student teachers' a priori beliefs often tend to be very much teacher-centered, behavioristic, and mainly focused on rote subject matter learning (Markic and Eilks 2012). These beliefs mostly exist in the student teachers' subconscious and can act as filters through which new information about becoming a teacher is influenced and thus can act as hindering factors in student teacher learning. Unfortunately, learning within many teacher training programs follows similar pedagogies and therefore tends to reinforce these beliefs. Considering the impact of beliefs about teaching and learning in general and in science education in particular, there is a need to make student teachers' prior beliefs explicit and to confront them with modern educational theory, e.g., from the field of constructivist learning and student activating pedagogies. Making these beliefs and initial concepts explicit and confronting them with modern educational theory and vignettes from the classroom can be a first point for initiating conceptual change (Markic and Eilks 2012). This process of explication can help student teachers become more aware of the importance of unconscious beliefs and concepts about teaching and learning.

Recognizing the Nature of Concerns

Based on a constructivist approach to teacher learning, research has revealed that student teachers are able to substantially change their beliefs from traditional to modern beliefs. A core issue for this change is to allow student teachers to be confronted by, and thoroughly reflect upon, modern teaching and learning practices – beyond the practices of the university – as soon as possible. In so doing, student teachers have been shown to develop and change their perspectives on teaching and learning (Hoy and Woolfolk 1990). However, when entering school for teaching internships or after finishing teacher education, prospective teachers are confronted by many concerns.

Student teachers most frequent concerns seem to be related to their own subject matter adequacy and their potential inability to answer pupil's subject-related questions. But also questions of discipline, pupils' reactions to them, or the evaluation of their lesson plans and expectations of their supervising teachers are also areas of major concern. In the case of internships or being a trainee teacher, the student teachers also have concerns about other aspects of adequacy and personal evaluation, e.g., about the frequency of visits and observations by supervisors and about being graded themselves as well as their grading of their pupils. That means before entering schools their main concerns are in the area of subject matter knowledge, general educational skills, and formal aspects of the teacher education program. Before entering school there is much less concern about those topics which are typically the main part in domain-specific educational courses in teacher education, like knowledge about instructional design, methods of presenting subject matter, or assessment of pupils' learning (Fuller 1969).

It has been shown that in the first weeks of teaching, student teachers are mostly concerned about themselves, whether they have sufficient subject matter knowledge or being able to keep discipline in class. A poorly developed background in subject matter knowledge leads to many concerns and a lack of self-confidence to teach science and to react appropriately to pupils' questions (Appleton 1995). Lack of routines about working with the pupils also hinders teachers' organization of domain-specific learning processes. That means, in teacher training, there is first of all a strong need to develop good and broad subject matter knowledge in the domain of later teaching as well as developing standard routines to manage classroom organization. Other than with the subject matter knowledge and the question of discipline, student teachers' concerns about specific issues of teaching and learning science also play a role and may appear amorphous and vague.

Teaching Experience

After experiencing teaching science during their first teaching experience, many naive concerns become more concrete and real. While student teachers prior to teaching are mainly concerned about their subject matter expertise or skills in classroom organization, following their initial experiences in teaching, concerns shift towards the learning of their pupils and their influence on it. Concerns change from the areas of subject matter knowledge or general educational knowledge towards concerns about the student teachers' pedagogical content knowledge. A student teacher who is not familiar with the subject matter will have difficulties developing pedagogical content knowledge, e.g., how to deal with student alternative conceptions or how to select suitable models for explanation. Sufficient subject matter knowledge is a necessary prerequisite for the teacher to ask appropriate questions, suggest suitable investigations, or to assess student learning. However, this knowledge about, e.g., appropriate tasks, pedagogies, or students' alternative conceptions is not a part of the subject matter knowledge alone but needs additional well-developed pedagogical content knowledge.

Within the domain of pedagogical content knowledge, student teachers first of all need to develop their knowledge about pupils and their learning. This knowledge can also be of use in modifying and reconstructing student teachers' images of themselves as a teacher and about their own learning in teacher education. This self-reflected activity accompanied by a growing body of knowledge can help them to develop procedural routines to integrate classroom management and domain-specific instruction. Often, preservice programs fail to address these tasks adequately (Kagan 1992) and so these concerns persist until the student teacher learns how to confront and address them at a personal level.

Cross-References

- ▶ In-Service Teacher Education
- ▶ Primary/Elementary Science Teacher Education
- ▶ Secondary Science Teacher Education

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Summative Assessment

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Keywords

Accountability; Assessment; External assessment; Large-scale assessment; Monitoring; Summative assessment

Summative assessment refers to assessments which seek to obtain comprehensive information about student competence in a domain (e.g., science) for an evaluation of student learning. Teachers use summative assessment at the end of a unit or school year to gather evidence about students' mastery of the content covered throughout the unit or school year as a basis for grading. These classroom-based summative assessments are closely related with the learning aims of the instructional unit and thus the curriculum. However, summative assessments are also used by other agents within the education system, such as policy makers. Policy makers, for example, use summative assessments for monitoring the efficiency of parts of the educational system (e.g., specific curricula) or the education system as a whole (e.g., in comparison to other countries' education systems). These external large-scale summative assessments are not directly aligned with curriculum. However, in order to serve their purpose to measure students' mastery of the learning goals laid out in policy documents at a particular stage in the education system, they should be related to a model of students' progression in mastering the learning goals. Summative assessments need to build on a model of student mastery of the domain. In the simplest case, such a model embraces two levels, non-mastery and mastery. Typically students are considered to have mastered the domain or a particular aspect of the domain (i.e., one learning goal) when they achieve a minimum score on a set of tasks representing the domain or the particular aspect of the domain. At best, summative assessments are building on a model embracing a hierarchy of levels indicating different levels of mastery each represented by a specific set of tasks. In case of external large-scale assessments, these tasks are typically multiple-choice or short-answer questions. In case of classroom-based summative assessments, these tasks may include multiple-choice items but are also often based on more complex open-ended items.

Cross-References

- ▶ Assessment: An Overview
- ▶ Formative Assessment
- ▶ Large-Scale Assessment

Sustainability and Science Education

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We live in the "Anthropocene" era, an era in which human activity plays a significant role in shaping conditions on our planet. In order to survive as a species on Earth, we need to monitor, understand, forecast, mitigate, and adapt with the changing social, economic, biological, geological, and physical conditions on Earth. Successfully addressing these vital challenges requires a continuously iterative process of learning, building, integrating, and using knowledge, including that of natural and social science and humanities throughout society. This recognition presents new challenges that necessitate restructuring the purpose, content, and approach of education. The focus in this entry is on changes needed in science education for this to contribute to a sustainable future for all.

The United Nations Decade of Education for Sustainable Development (2005–2014) aimed to raise awareness internationally of the need for education that supported the multiple goals of sustainable development, as articulated prominently in the 1987 Brundtland Commission document *Our Common Future*. Sustainable development is defined by the Brundtland Commission as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The term "development" is hotly debated in this context, with questions as to whether it should refer to human well-being, rather than only to the use of diminishing physical resources and the raising of Gross Domestic Product figures. The meaning of sustainability and sustainable development will continue to evolve and be debated. Nonetheless, the broad concept and the fundamental uncertainty of an evolving understanding of a rapidly changing world urgently direct our attention to changing how education can help humanity cope and adapt with the changes.

Important changes in science education – and indeed in all areas of education from preschool through lifelong learning – are needed to continue to prepare students to play a role in advancing knowledge in the sciences and, equally importantly, prepare children and adults to make informed decisions and take individual and collective actions in effecting a transition to a sustainable future for all on the planet.

Science education needs to adapt to fulfill the needs of society in the near and far term. The critical issue is adaptation to a changing paradigm of science, a new one that fully embraces a mix of mono-, multi-, inter-, and transdisciplinary research, that enables social innovation as well as marketing-driven technological innovation, that recognizes and incorporates a diversity of sources and forms of knowledge, that addresses ethics and values in the conduct of and choice of research in science, and that enables and encourages meaningful dialogue with stakeholders in society at large.

What then are the key elements of this new paradigm of science?

In addition to domain-specific knowledge from expertise in narrowly focused "silos" of science that is the core of the reductionist approach, multi-, inter-, and transdisciplinary science and systems thinking that draws more broadly from social and natural sciences and humanities perspectives is essential for addressing the complex challenges of a rapidly changing global system. Complex challenges – ones that involve a system or systems in which the components are coupled nonlinearly with feedback loops and time delays – require a system-level, holistic approach. Simply summing the behavior of the components does not provide an adequate understanding or description of the whole system. Since we as humans are inseparable and significant actors in the complex socio-ecological system of the planet, this makes the need for integrative, multi-, inter-, and transdisciplinary science processes essential.

Models and scenarios built from the output of models are essential tools in understanding complex systems. They facilitate our thinking about complex issues, which are generally characterized by both qualitative and quantitative information from multiple sources and high degrees of uncertainty in the information. Models are fundamental to the way human beings think. They are approximations of the behavior of phenomena and events of the world and reflect perceptions of patterns and efforts to categorize, explain, and predict future behavior of physical, biological, social, and economic phenomena and systems. Models are essential in organizing and interpreting information, whether implicit and intuitive, or elaborate mathematical constructs. Models are becoming increasingly important in social sciences, not only in natural sciences and engineering, where they are well-established tools (Klüver 1998; Lehrer and Schauble 2000). On one end of the scale, models may be greatly simplified associations, elaborated metaphors, or mental representations, or at the other end of the scale, they may be highly elaborated mathematical and computational constructions, such as system dynamics or agent-based models. The results produced from these models do not give "the answer," nor can they. What the results can provide is a set of potential options and new insights to be weighed and considered with due regard to stakeholder values, local conditions, and the fundamental limitation of any model as an approximation to address a specific question and fed by imperfect data.

Transdisciplinary science includes relevant stakeholders – i.e., those who may exert influence on or be influenced by the issues under consideration – in framing the research questions; collecting, analyzing, and interpreting the data; and communicating the knowledge developed through the research. This approach creates important opportunities for mutual learning among the researchers and the community in which the research occurs, thus potentially leading to more informed and effective public and policy decisions and actions. It also allows for discussion and consideration of the multiple values that typically characterize the views of societal actors, including the scientists themselves, regarding any given issue for scientific research.

How can science education develop and improve in the context of the Anthropocene and the new paradigms of science?

The structural and curricular changes in science education needed to respond to this new paradigm of science include the following:

- Improving and expanding problem-focused, project-based learning that draws upon multiple domains of knowledge as needed for the problem at hand
- Developing stronger collaborative and communicative skills
- Building an understanding of the uses and processes of modeling in science
- Incorporating greater consideration of social, ethical, and cultural aspects and implications of science and technology

Greater emphasis on learning to learn and learning critical thinking, rather than relying on mastery of an expansive but shallow knowledge base, is not a new issue and is not tied to sustainability, per se. Nonetheless, improvement in these aspects of learning is sorely needed to support learning that strengthens resilience and adaptability.

A key structural and curricular change needed in science education to respond to this new paradigm of science is change in the desired forms of learning, a change that maps onto the changes in science *per se* – from reductionist and convergent and bounded by the discipline divisions of the past to expansive, collaborative, and transdisciplinary.

These changes can be implemented at every level of education from preschool through tertiary education and in informal and lifelong learning contexts. Developing coherent pathways of learning from early childhood through university and lifelong opportunities should be a high priority in order to give learners at every stage of development a connected and progressively more focused set of thinking skills, knowledge, and insights. Of course, education of teachers and continuing professional development must be a major part of any strategy for any substantive educational change, and that is equally so here. So too, expanding change from an isolated lesson about change to design and daily practice in the operation of the classroom, school, and education system in each community or region is crucial (see, e.g., Stone 2009). New patterns of behavior and operation are far stronger "lessons" when seen and experienced in the daily environment than when presented only in abstract, didactic forms.

There are many examples of successful efforts to implement these approaches in many locations around the world, and a number of resources are available to support the transformation of education at various levels and different conditions and cultures. A few examples follow to indicate the range of efforts, levels, and materials available.

Encouraging students to engage with their community as part of their science education projects – e.g., measuring noise levels or collecting airborne particle samples on a filter in heavy-traffic areas and conducting citizen response to the measurements as surveys – provides experience with multi- and transdisciplinary science. This transdisciplinary research in which students are the stakeholders, as are the teachers and parents and members of a community, not only can change the motivation of students to engage more deeply with the science, but also give them practical experience in applying multidisciplinary knowledge and challenge theoretical knowledge with real experience. In yet another regard, this type of activity lends itself well to constructing and using computational models at age-appropriate levels to interpret the data gathered. This kind of activity has also been at the heart of some after-school programs and summer camps with an environmental focus.

Social choices can also be used to introduce modeling, starting with elementary school-age children. An example that engages children in modeling and empirical testing of their model is to build a simple model to illustrate and predict decision making by one of their cohorts. Ask a class where they think a certain child in another class will sit in the lunchroom tomorrow. Starting with a simple diagram of the space, including the entrance normally used, tables can be assigned with letters and chairs at the table numbered. Children will usually either just quickly guess a location or say they don't know. If they are asked what do you see when you walk in the lunchroom and what might make you choose one seat or another, then the class will start suggesting possible decision factors, such as the location of a supervisory teacher, being near a particular friend, being far from groups of younger or older children, distance from the end of the lunch line, or proximity to the windows. The factors are written on the board or set of cards. Once this process of elaborating factors that influence where someone might sit is completed, the factors can be ranked by priority. Out of this a simple decision tree can be illustrated. Then, the children can test their model by observing the path and choice of the child at lunchtime and later critiquing the model based on the outcome of their observations.

Modeling as a strategy for learning physics at the university and high school level has been strongly advocated (Jackson et al. 2008) and demonstrated and extensively tested in introductory courses using computational modeling (Chabay and Sherwood 2011). Computational agent-based modeling in social sciences has also been implemented at the tertiary and to a lesser degree at secondary levels by Marco Janssen and colleagues at Arizona State University.

Computer and mobile app games already on the market or readily modified versions of commercial games have been used in programs in and out of schools to involve students in a creative and learning processes (see http://www.futurelab.

org.uk/sites/default/files/Computer_games_and_learning.pdf). Since game engines actually are forms of computational models, they can be used to provoke discussion and exploration of how models can be used for decision making. In the wide and growing array of computer games now burgeoning on mobile platforms, games built upon models of politics and business have become "fair games," too.

A number of universities have formed partnerships with schools from preschool through secondary school in their communities and regions to support science education and other areas of learning. These provide incentives to students, particularly for minority and disadvantaged youth to stay in school and form relationships with higher education institutions. This creates an important, though often quite difficult, step in building a more coherent pathway through the educational landscape.

Informal learning environments – e.g., after-school programs, museums and science centers, public science events, and specialized camps – are very important in the landscape of science education (http://www.astc.org/sciencecenters/index.htm). Not only do they provide additional science learning experiences, often with good social, collaborative, multidisciplinary project focus, but they also create links with parents and other adults who become engaged in new experiences of science through their children or as part of adult groups. Science centers and museums are also important potential partners with global change research institutions and programs in that they can function as boundary institutions between local stakeholders and the researchers for mutual learning process.

Cross-References

- ▶ Integrated Science
- ▶ Learning Science in Informal Contexts
- ▶ Science for Citizenship
- ▶ Socioscientific Issues

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Talk and Science Learning

► Discourse in Science Learning

Tangible and Embodied Interactions for Learning

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Keywords

Augmented reality; Embodied learning; Immersive environments; Tangible interactions

Main Text

The goal of bridging the digital/physical worlds for purposes of learning has been pursued by science educators for more than 30 years, grounded in the work of Seymour Papert (e.g., 1980) and his work at the MIT Media Lab. One such project was that of LEGO/Logo (e.g., Resnick and Ocko 1990) which allowed children to become the designers and creators of their own physical interactive machines (e.g., robots, motorized cars, motion detectors, and various other simple digital transducers). Related efforts, using simple programming languages such as Squeak and Scratch, have enabled even young children to create software applications that control or coordinate such devices. For example, students could use Scratch language to program a computer-simulated race car and track, then build a real steering wheel using a paper plate that controls the race car by physically turning the wheel. Public interest has grown rapidly in such technologies, with students and citizens of all ages inspired to create compelling new forms of interaction with their physical or virtual environments. Active communities of “makers” have grown, fueled by “maker fairs” (conventions of enthusiasts), hackathons (an event where designers and developers come together and work on a shared project, such as software development for an educational purpose), and online exchange sites. Increasingly accessible hardware products have emerged, like the Arduino microprocessor kit and Makerbot 3D printer, which facilitate design and development efforts within these creative communities. In 2014, *Thingiverse*, an online maker portal, has over 50,000 open-source, user-contributed projects, illustrating the vibrant, active, and social nature of maker communities. This entry describes three forms of technology applications that hold great promise for science education: (i) embodied interactions

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Tangible and Embodied Interactions for Learning, Fig. 1 With Arduino microprocessor and simple circuits made out of any conducting medium (including bananas), the sky is the limit of creative applications for tangible and physical computing

between the learner and her environment, (ii) augmented reality applications, and (iii) immersive environments.

Embodied Interactions for Science Learning

The term "embodied interactions" has been advanced to describe how students acquire knowledge of the world around them through bodily interaction with their physical environment (Barab and Plucker 2002). Recent advances in touch surface technologies, including Apple's iPhone and iPads, Microsoft's multi-touch surface computing, and interactive white boards have introduced new ways of sensing and manipulating our environments (Ishii 2007). Interactive wands like the Nintendo Wii allow users to control and manipulate images and events on large screens or projections by pulling, turning, flicking, or touching them. With the introduction of the Microsoft Kinect, users can now directly interact with computer-projected images or the wider three-dimensional surround, using computer vision that tracks their movements within the space – responding as they wave their arms, or interact with both real and virtual objects. In addition to early applications for interactive forms of gaming, these new technologies allow research of new forms of learning interactions. Science education researchers are now creating learning activities where students engage physically with their environment, moving or sorting tangible objects (i.e., that are tracked using computer vision), or interacting physically with virtual objects or environments. These activities engage students in exploring personally relevant and interesting topics such as climate change, ancient civilizations, or cooking.

Augmented Reality

Another emerging area within science education research is that of augmented reality, where information is mapped onto the physical environment, with additional layers of information allowing the learner to gain personally or contextually relevant information. Smartphones or tablet computers, with their built-in GPS features, make it easy to provide the learner with location-dependent information, allowing enriched experiences of museum visits, field trips, or a walk down the street. An application running on the learner's device (e.g., a custom "app" or a Web site within the phone browser) would present contextually relevant information, corresponding to the learner's physical location. Information can also be filtered so that it addresses the individual learner's specific interests or needs, adding a contextual layer. The smartphone's inertial detectors (i.e., the features that allow the screen image to "flip" when the phone is reoriented) or its built-in compass can also be employed as a means of allowing directional orientation. Research of augmented reality for science learning is still in its infancy, but is already playing a role in museum experiences, citizen science projects, online communities, and other forms of science learning.

Tangible and Embodied Interactions for Learning, Fig. 2 Large screen projections around the room displaying the immersive simulation as well as audio tracks of natural rainforest sounds transform a smart classroom into a rainforest in Southeast Asia

Immersive Environments

A final dimension of tangible and physical interactions for science learning is concerned with immersive environments. Early efforts explored online experiences, where students log into an Internet-connected computer-based environment, appearing as avatars (stylized representations of themselves, typically in cartoon format), giving the user a sense of presence, navigation, and interaction with others and with objects in the environment (e.g., similar to Second Life or World of Warcraft). In the *River City* project (Dede 2009), students enter a simulated nineteenth-century community where a mysterious disease is devastating the citizenry. Working collaboratively, and with assistance from helpful denizens and a variety of embedded clues and scaffolds, students must design and conduct experiments that help them isolate the cause of the (water-borne) disease, developing an understanding of the relevant biology and scientific practices. More recently, science educators have leveraged the physical environment to create immersive or embedded simulations, such as *EvoRoom* (Lui and Slotta 2012) where learners enter a room-sized simulation of a Sumatran rainforest, created using projectors that fill the walls with animations of various flora and fauna, as well as ambient media (audio track of insects, and even olfactory stimuli). Scaffolded by handheld tablet computers, students move physically around the room, collaborating with peers to investigate various flora and fauna as they evolve over 200 million years. This approach provides students with a powerful new form of embodied learning where they may develop a deep understanding of evolutionary processes (Figs. 1 and 2).

Cross-References

- ▶ Handheld Devices
- ▶ Immersive Environments
- ▶ Interactive White Boards
- ▶ Technology for Informal and Out-of-School Learning of Science
- ▶ Technology for Science Education: History
- ▶ Technology for Science Education: Research

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Teacher Contextual Knowledge

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Keywords

Ethical, political, economic, and social factors; Pedagogical content knowledge; School culture

We define *teacher contextual knowledge* as simply knowledge of the context of teaching, where the context of their teaching includes who they teach (their students), where they teach (their classrooms, schools, communities, and so on), and what they teach (the school subject, the level, the curriculum, and its relationship to local, state, and national standards). Given this, teachers' contextual knowledge is acted upon by the ethical, political, economic, and social factors that influence teaching and learning in schools. It should be clear then that to recognize the importance of teachers' contextual knowledge is to reject "one size fits all" education initiatives (e.g., standardized curriculum) that assume that effective science teaching is context independent. In the remainder of this small entry, we provide a brief overview of the literature related to science teachers' contextual knowledge.

Although there is a more than 100-year history of research in science education, it is only during the past 25 years or so that attention has been paid to what teachers know, how they come to know it, and how they use their knowledge in the classroom. More recently, attention has been paid to not only the content of teachers' knowledge but also the context within which they teach. The importance that science educators place on knowledge of the context of teaching can be seen in the number of chapters devoted to it in the most recent *Handbook of Research on Science Education* (Abell and Lederman 2007).

Shulman developed the idea of pedagogical content knowledge (PCK) as consisting of repertoires that teachers have of the ways in which they can represent subject matter knowledge to their students. PCK includes teachers' knowledge and beliefs about the purposes for teaching a particular subject, knowledge of students' understanding of the subject matter, knowledge of the curriculum, and knowledge of instructional strategies. Knowledge of the context of schooling was seen to be distinct from PCK. Science educators early on embraced the notion of PCK and began to see the importance of the context of teaching and its relationship to PCK, such as the ways in which knowledge of educational contexts contribute to teachers' PCK (Gess-Newsom and Lederman 1999).

In 2001 Barnett and Hodson (2001) put forth a model of pedagogical *context* knowledge. Drawing from prior literature, this model describes the ways that science teachers can construct and employ an amalgamation of academic and research knowledge, pedagogical content knowledge, professional knowledge, and classroom knowledge while contemplating, designing, and implementing their science teaching in shifting and varied educational contexts. Specifically, Barnett and Hodson (2001) point out that teachers must learn about and navigate several interacting "microworlds" (e.g., science education, teacher professionalism, science curriculum, and school culture), each with its own culture and particular "knowledge, language, methods, rationality, criteria of validity and reliability, and values" (p. 440). In their model, teachers need to also consider, reflect upon, and determine the origins of their personal frameworks, skills, and beliefs. When science teachers gain the ability to navigate these microworlds and their own belief systems, they can use pedagogical context knowledge to develop a cultural awareness that involves “a) understanding the social location of particular clusters of beliefs and practices; b) acknowledging the context-dependence of most of what they think and do; and c) recognizing the existence of different modes of discourse, each having a distinctive sociocultural origin” (p. 440).

In addition to the work on teacher knowledge, there is a large set of literature in science education that looks at the relationships between context and the teaching and learning of science. This literature considers factors such as issues of racial, ethnic, language, culture and socioeconomic diversity, gender, setting, and how these factors intersect with the cultures of teachers and schools (Abell and Lederman 2007). Although discussions of teacher contextual knowledge allude to these factors, this other literature places them in the forefront of what teachers need to know and consider as they work within the highly diverse settings of contemporary schooling.

Cross-References

- ▶ Pedagogical Content Knowledge
- ▶ Secondary Science Teacher Education
- ▶ Teacher Craft Knowledge
- ▶ Teacher Professional Development
- ▶ Teacher Research

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Teacher Craft Knowledge

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Keywords

Practical knowledge; Wisdom of practice

Craft knowledge is one of the missing pieces in the puzzle of high-quality teacher education and professional development. Craft knowledge develops as one makes sense of experience, but experience is limited or absent from many education courses (for preservice teachers) and professional development events (for those who are already teaching). Grimmett and MacKinnon’s (1992) definitive review of craft knowledge in the context of the education of teachers offers this perspective: “Craft knowledge represents intelligent and sensible know-how in the action setting” (p. 395). “Craft knowledge is essentially the accumulated wisdom derived from teachers’ and practice-oriented researchers’ understanding of the meanings ascribed to the many dilemmas inherent in teaching” (p. 428). Barth (2001) offers a similar interpretation: “*Craft knowledge* is the massive collection of experiences and learnings that those who live and work under the roof of the schoolhouse inevitably accrue during their careers” (p. 56). These statements confirm that craft knowledge is intimately linked to action, not to books and research reports; thus, it is knowledge that is not easily recognized, documented, or shared in the ways that propositional knowledge can be. Barth (2001) makes an important further comment: “Craft knowledge is rarely viewed by school people *themselves* as legitimate, rigorous, or useful” (p. 57). Neither the school-and-classroom culture nor the university culture readily acknowledges and celebrates the value of a teacher’s craft knowledge. The university’s difficulties in recognizing craft knowledge are apparent in its emphasis on the importance of research and publication, with little more than lip service to the development of excellent teaching skills.

In the context of science teaching, craft knowledge includes all that the teacher is able to do, from at least two major perspectives – science and pedagogy (the interaction between teaching and learning). From the perspective of science, teachers' craft knowledge includes the ability to manipulate scientific equipment successfully for teaching purposes and to recognize in each piece of equipment the scientific concepts that made it possible and thus are embedded within. From the perspective of pedagogy, craft knowledge includes the ability to identify what students already know and then construct experiences that will enable them to move their existing understandings closer to accepted concepts of science.

In the context of science teacher education, there are many challenges to the development of craft knowledge within traditional structures of preservice programs. Typically, those learning to teach spend much more time in education classes than in practicum classrooms. Developing craft knowledge requires firsthand experience of engaging students directly with equipment and with both familiar and novel teaching procedures. Those learning to teach have long valued practicum experiences more than education classes; perhaps they have realized intuitively that the craft knowledge they long to develop and master requires them to be active in a classroom. Only when individuals are active can strategies of reflective practice be invoked to interpret and consolidate what one is learning from experience.

Knight (2004) has attempted to capture the physics teacher's craft knowledge in a unique book that devotes a full chapter to each of the 21 major topics in the basic physics curriculum. In addition, he offers five specific principles to guide teachers' actions; these "five easy lessons" are not easy, but they are specific, practical, and grounded in recent research. One is "Focus on phenomena rather than abstractions" (p. 42); a second is "Deal explicitly with students' alternative conceptions" (p. 43). Knight provides detailed accounts of students' typical conceptual difficulties as well as teaching approaches (including experiments and demonstrations) that help to overcome conceptual difficulties. Because experience is required to appreciate the accounts of craft knowledge, books such as Knight's may be of more immediate value to practicing science teachers who already have considerable firsthand experience of the many ways in which students can misinterpret their previous experiences (which generate a kind of early craft knowledge) and their teacher's efforts to guide them to more useful interpretations. Similarly, the Project for Enhancing Effective Learning (http://peelweb.org) is an excellent source of written accounts of teachers' craft knowledge, with many contributions by science teachers describing teaching procedures that engage students in ways that foster metacognition rather than passive learning. These accounts may inspire further developments of a teacher's craft knowledge.

The craft knowledge of the science teacher educator who understands and values craft knowledge will include strategies for helping prospective teachers to understand and respect the differences between more familiar propositional knowledge and more tacit craft knowledge. Thus, the educator's craft knowledge would include structuring experiences and assignments that help beginners to describe and share craft knowledge gained in science classrooms. It would also include making explicit one's own craft knowledge as a teacher educator in order to model future professional development of craft knowledge.

Cross-References

- ▶ Pedagogical Content Knowledge
- ▶ Pedagogical Knowledge
- ▶ Project for Enhancing Effective Learning (PEEL)
- ▶ Science Teachers' Professional Knowledge
- ▶ Teacher Contextual Knowledge

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Teacher Educator as Learner

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Keywords

Education; Knowledge; Learning; Teacher Knowledge

Introduction

The concept of a teacher educator as a learner might initially seem strange. After all, those entrusted with the task of teaching future teachers might be reasonably expected to have at least three particular kinds of knowledge: knowledge of disciplinary content, knowledge of how to teach disciplinary content (pedagogical content knowledge), and knowledge of how to teach others how to teach disciplinary content. By this rationale, knowledge of how to teach teachers requires mastery over both disciplinary content knowledge and pedagogical content knowledge. In short, one might expect that being a teacher educator requires knowledge of what it means to be a successful teacher in a particular content area, which also implies in-depth propositional knowledge of how to teach particular scientific concepts.

Professional Knowledge of Practice

A considerable amount of research in recent decades has problematized the view that knowledge of teaching, and thus knowledge of teaching teachers, is based purely on propositional ways of knowing. Beginning with Schön's (1983) work on knowing-in-action via reflection-in-action, a number of research programs have explored the ways in which teachers construct professional knowledge of practice from an *experience-based* standpoint. These studies have recognized that teachers construct a considerable amount of knowledge from professional experiences, particularly those experiences that are puzzling and novel or do not lend themselves to easy solutions. Teachers' professional knowledge might also be considered craft knowledge, created in a reflexive relationship between the teachers' explicit actions and their professional contexts.

One significant problem of naming and interpreting teachers' professional knowledge is that it is largely *tacit and unexamined*. Although teachers make any number of decisions and take numerous actions in the course of their duties as a classroom teacher, it is less clear that teachers can explicitly articulate why they chose to act in particular ways in particular situations. Loughran (2007) makes a strong case that science teachers should be supported as learners in their own right, so that they might understand and be able to explain the nature of their pedagogy in more nuanced ways – perhaps through action research – and thus enhance the quality of their students' learning.

Teaching Teachers

These ideas can be productively extended to the concept of teacher educator as learner in several ways. First, considerable evidence presented in the literature on the development of teacher educators demonstrates that experiences teaching in the elementary and/or secondary school systems are *not* sufficient preparation for the task of teaching teachers. There is something unique about the knowledge required to teach teachers that is different from the knowledge required to teach K-12 students. Second, knowledge of teaching teachers is, by and large, tacit and thus not as highly valued as other kinds of knowledge found in the academy (e.g., knowledge of a particular research discipline). Third, effective teaching often looks easy to the layperson; everyday classroom experiences often mask the deep professional knowledge required to make a learning experience productive. Knowledge of the discipline of teaching is not obvious. Neither K-12 students nor teacher candidates typically understand the complexity of making deliberate pedagogical moves; they have not developed the ability to link teaching strategies with learning effects.

Self-Study of Teacher Education Practices

A group of like-minded teacher educators came together in the early 1990s to offer the ways in which they had reframed their approach to teacher education to *teacher educator as learner*. This move occurred at the end of a decade of work encouraging teachers to reflect on their practice and thus to become learners, and the group's early motivation was partly a desire to model the behaviors they expected of their teacher candidates. The result is a research program known as Self-Study of Teacher Education Practices (S-STEP) (Loughran et al. 2004) that explicitly casts the teacher educator as a learner with the purpose of describing, analyzing, and interpreting individual and collective pedagogies of teacher education. Although S-STEP does not have an exclusive claim to the idea of teacher educator as learner, it is unique in that it explicitly requires its practitioners to investigate their own practices systematically and to make their learning about teaching teachers public and subject to the scrutiny of fellow researchers.

Self-study research tends to challenge an individual's prior assumptions about teaching and learning and be self-initiated, aimed at improving pedagogy, and result in making tacit knowledge explicit. Many self-studies involve a reflective turn, sometimes called a turn back to self, in which teacher educators explicitly state the ways in which their views about teaching teachers have changed as a result of conducting self-study research.

Self-study methodology is notable because it formally casts the teacher educator as a learner and makes the results of her or his investigations public to the research community. Despite the label of "self," many self-studies involve collaborating with critical friends – including other teacher educators and teacher candidates. Self-study takes seriously Loughran's (2007) assertion that science teachers and science teacher educators should "(a) challenge the taken-for-granted in their practice; (b) examine, articulate, and disseminate their learning through experience; and, (c) seek to continually ensure that practice and theory inform one another" (p. 1059).

Self-study research conducted with input from teacher candidates provides one way that teacher educators can model explicitly the practices they expect from their students. Knowledge of teaching is not static and it requires a teacher/teacher-educator-as-learner stance to discourage complacency and to develop an "authority of experience" (Munby and Russell 1994) over one's knowledge of practice. Several good examples of science teacher educators as learners are evident in the edited collection by Bullock and Russell (2012) which captures the essence of the authors' learning about the teaching and learning of science.

Cross-References

- ▶ Pedagogical Knowledge
- ▶ Pedagogy of Teacher Education
- ▶ Self-Study of Teacher Education Practices (S-STEP)
- ▶ Teacher Research

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Teacher Preparation and Indigenous Students

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A Note Regarding Terminology

There are multiple ways to represent "indigenous" cultures. Because this description is meant to represent an international perspective, the term indigenous is used with the understanding that locally accepted conventions and contexts reflect heterogeneity. Therefore, it is imperative to seek advice from local people about local conventions and contexts for terminology.

Challenges in Preparing Teachers to Teach Indigenous Students

Relationships between the institution of education and indigenous communities are quite complex. Many indigenous community members are frustrated by what some would call "neglect" of indigenous education and the lack of success for their students in the school system. For many indigenous cultures, the institution of school has been associated with strong negative feelings. Historically, teachers and schools were often at the front line in attempts to assimilate indigenous students (Brayboy and Maughan 2009). In many countries these attempts resulted in children being taken from their families and forced into residential schools. Although assimilation attempts are no longer an explicit part of current approaches (see acculturation), they are part of the history of the institution for indigenous communities and can contribute to negative feelings about school. Further challenges associated with indigenous students and schooling stem from a lack of alignment between current science teaching, assessment, and curricula with *indigenous knowledge* and *values*. An indigenous approach can be characterized by collective decision-making, sharing, and flexible conceptions of time, for example, which can be in direct conflict with a mainstream science approach. The clash of these different knowledge systems can be a challenge for students, communities, parents, indigenous education workers, and teachers. The clash is further exacerbated when nonindigenous teachers attempt to teach without an understanding of how to incorporate indigenous knowledge and values in the taught curriculum. In addition to challenges associated with the institution of education and the science curriculum, challenges also stem from the nature of teacher preparation programs themselves. Teacher education programs are typified by a full curriculum with little room for additional content, making it difficult to address issues associated with indigenous education. Even more important, students in teacher preparation programs are in the beginning stages of their own professional self-identity and may not have the necessary background experience or opportunity to reflect on their role in teaching indigenous students.

Indigenous Ways of Knowing and Preparing Teachers to Teach Science

One way to address challenges associated with multiple worldviews is to use a two-way teaching and learning approach. Two-way teaching and learning emphasizes collaborative connections among members of indigenous and nonindigenous cultures. With this approach, each culture is seen as having a great deal to learn from one another and learning is seen as a two-way transaction (Purdie et al. 2011). Fundamental to two-way teaching and learning in science is the understanding that indigenous students need to know and use nonindigenous science, but not at the expense of their own culture and knowledge. Similarly, nonindigenous students benefit from learning worldviews and knowledge systems different from their own. Although this approach is especially difficult in the tertiary setting, it can be achieved if prospective indigenous teachers are able to share their knowledge (see, e.g., Brayboy and Maughan 2009).

Science is especially suited for two-way learning and teaching because there can be areas of "common ground" in science content knowledge and indigenous knowledge systems. For example, students' observations and inferences regarding the natural world represent key components of skills and procedures in both science and indigenous knowledge systems. Recognizing and valuing this common ground between science content knowledge and indigenous knowledge has been an emerging point of interest with both nonindigenous and indigenous scientists working with indigenous communities in data collection, environmental impact assessments, and risk management plans (see, e.g., Indigenous Knowledge Systems at http://ankn.uaf.edu/index.html). Students, teachers, and education support staff would benefit from recognizing that students may have this place-based knowledge (Chinn 2012) and that science is not about worksheets and definitions or a separate discipline reserved for a few others. Instead, science curricula that value and incorporate indigenous knowledge are especially suited for helping facilitate science learning in school classrooms. However, without teachers' knowledge of *how* to incorporate indigenous knowledge in the taught science curriculum, activities or science content commonly becomes "bolted on" ideas that can caricaturize the content rather than lead to two-way understandings (see, e.g., http://8ways.wikispaces.com/Cultural+content). It is therefore essential that indigenous knowledge systems and the nature of science are included in the science methods' training provided in teacher preparation programs. At the same time, even if prospective teachers attempt to include indigenous science in their teaching, it is difficult for nonindigenous teachers to teach science to indigenous students. Prospective (and, arguably practicing) nonindigenous teachers need help on learning how to become culture-brokering teachers in order to understand students' prior knowledge and indigenous ways of knowing (Aikenhead and Michell 2011).

Cross-References

- ▶ Acculturation
- ▶ Borders/Border Crossing
- ▶ Cultural Influences on Science Education
- ▶ Cultural Values and Science Education
- ▶ Culture and Science Learning
- ▶ Indigenous Knowledge
- ▶ Indigenous Knowledge Systems and the Nature of Science
- ▶ Indigenous Students
- ▶ Multiculturalism
- ▶ NOS: Cultural Perspectives
- ▶ Science Curricula and Indigenous Knowledge
- ▶ Values and Indigenous Knowledge

Useful Links

8 Aboriginal Ways of Knowing. http://8ways.wikispaces.com/

Aboriginal Education Research Centre University of Saskatchewan. http://aerc.usask.ca/

Alaska Native Knowledge Network. http://ankn.uaf.edu/index.html

Indigenous Science Network, Australia. http://members.ozemail.com.au/~mmichie/network.html

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Teacher Professional Development

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Keywords

Pedagogy; Education; Research; Teacher Education

Teacher professional development includes experiences designed to enhance practicing teachers' knowledge, attitudes, and skills, including science subject matter, new pedagogical approaches (teaching strategies and methods), alternative student assessments, use of technology, methods to teach students about scientific practices and nature of science, and more. The purpose of professional development is to ultimately enhance learning of students and their views of science. This is not to say that teachers are not professionals, and on their own accord, they do not strive to be the very best teacher. The growing knowledge base of teaching gives a reason for professionals to stay current with the ever-changing field of education. Currently, there is a great deal of interest in designing effective professional development experiences, given the explosion of scientific information, research on student learning, and increasing challenges of teaching diverse children in classrooms. During the years following a teacher's initial certification or license to teach science, it is important (and usually required by school districts/jurisdictions) for a teacher to continue to learn about new initiatives and findings in science and in education. These may include new learning technologies, the latest scientific discoveries in their fields, innovative science curricula, and new approaches to teach science. Professional development programs should provide teachers with continual learning experiences, as they continue their journeys to become highly effective teachers.

Variation in Programs

The range of professional development programs is great. These programs vary in many ways, including duration, content, and mode of delivery. Professional development programs differ in length from half- or single-day workshops to intensive multi-week programs, to full summer programs, and even to multiyear programs. The focus of a professional development program may be a particular science domain, such as biology, earth science, or physics, or an educational area such as inquiry, nature of science, use of learning technologies, differentiating curriculum for learners from diverse populations, or a combination of any of these. The mode of delivery may be face-to-face or remote online delivery. The location may be a teacher's school, museum, university, or science education conference site, or a teacher may go into the field or scientific research laboratory. In some cases teachers are immersed in learning science, through helping to carry out scientific research studies and/or in educational activities such as developing or adapting innovative curriculum. Many science teachers do not value professional development programs that are focused on general instructional approaches or educational issues, as much as those programs focused on science as content. There are recent studies that provide empirical evidence of the importance of science content knowledge in professional development programs for science teachers. Evaluators suggest that designers of professional development experiences (1) be clear about purpose and goals, (2) consider if the goals are worthwhile, and (3) account for how the goals will be assessed (Guskey 2000). The professional development experiences need to be systemic. In this sense, stand-alone, disconnected, and one-shot workshops do not necessarily align with overall policies of a teacher's school and may have limited long-term impact on a teacher.

The goal of professional development is teacher learning, including enhancement of knowledge of subject matter or pedagogical approaches, resulting in students' understanding science concepts and principles or developing greater understanding of scientific practices and nature of science. Almost two decades ago, Bell and Gilbert (1996), as reported in Hewson's (2007) review, studied 48 teachers related to their personal development, social development, and professional development over 3 years. Since this report there have been a plethora of reports examining different professional development programs in the United States and countries around the world, in order to better support teachers in the increasing challenge to teach diverse students in classrooms about science in our ever-changing world. Various elements in a professional development program include setting of goals, planning, enacting, looking at outcomes, and reflecting on the entire process (Loucks-Horsley et al. 2010).

Characteristics of Professional Development

Research studies have revealed that certain characteristics of professional development programs can significantly impact teachers. Characteristics that appear to effectively impact teachers include having a clear focus on science content, how students learn this content, and opportunities for teachers to be active learners of new content, which include teachers from the same school as participants, and for teachers to take on leadership roles. However, there is limited research at this time that provides direct evidence that connects these characteristics with increased student achievement. When planning professional development experiences, there are certain components identified by researchers to be very important. Components that professional developers should consider include the nature of the planning process, beliefs underlying effective professional development, the context of the professional development, and strategies deemed to be effective (Loucks-Horsley et al. 2010). In evaluating a professional development program, the evaluator should avoid common mistakes that include the following: (1) documentation is made instead of an evaluation; (2) shallow measures are used that are not true indicators of success; and (3) the time of the evaluation is too short (Guskey 2000).

Researching Professional Development

Research studies include small and large studies. In large-scale studies, participating teachers have identified some features of "best practices" in professional development. It is clear that one-day or short-term workshops are not as effective as sustained and intensive professional development experiences. Other important features include coherence of professional development goals and experiences with teachers' goals and school, state, and federal standards. Professional communication with teachers is also important. In regard to teacher professional development programs that focus on reform-based practices, such as teaching science as inquiry, Capps et al. (2012) conducted a critical review of the literature. These researchers concluded that although there are many reports of programs describing various features and outcomes, there were few empirical studies about professional development programs focused on inquiry instruction published in peer-reviewed journals. More empirical studies are needed specific to this area, given that teaching science as inquiry is an area of mainstream reform in science teaching.

Reform

As countries strive to carry out reform in teaching science, it is apparent that the teacher should be at the center of the reform. A major challenge for researchers is to demonstrate a link between a particular professional development model and the enhancement of teachers' knowledge; their beliefs of science; pedagogy; intentions to change their teaching methods; changes in actual classroom practice; and, ultimately, increased student achievement. It is important to shift research based on only teachers' self-reports to data based on classroom-based research. In that case researchers visit classrooms, as teachers carry out their new lessons. Actual classroom observations are conducted and analyzed. At this time, little empirical evidence exists that definitively demonstrates the effectiveness of one teacher professional development model over another. More studies are needed that utilize data across these four areas: teacher knowledge and beliefs, teachers' intentions, teachers' practices, and their students' learning. Although we have early case studies of single teachers, classrooms, and groups of students that lay the foundation for evaluating various kinds of professional development programs, more studies are needed that use quasi-experimental or experimental approaches. It is important to consider the context of the professional development program. In addition it would be very useful for researchers to carry out synthesis studies in the area of professional development. High-quality professional development programs may be expensive. We need to view professional development as an ongoing process and one that is complicated. We need to value and commit to investing in sustained and effective experiences. Otherwise, it seems unlikely that major changes will take place in science classrooms. Finally, it is important for researchers to communicate their findings to policy makers and stakeholders, in clear language, in order that investments can be made in effective programs.

Cross-References

- ▶ In-Service Teacher Education
- ▶ Project for Enhancing Effective Learning (PEEL)
- ▶ Science Teaching and Learning Project (STaL)
- ▶ Teacher Research

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Teacher Research

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Keywords

Feedback; Learners; Research; Teacher Learning; Teachers as Researchers

Introduction

Consistent with Hannah Arendt's (1958) revelation that scholars have valued theory production to a greater extent than improved practice, it is reasonable to assert that research should provide balanced outcomes that yield deeper understandings of education and improved practice. In addition, teacher research can be viewed as an essential requisite of professional practice, a central role that occurs continuously. If teacher research is to attain goals of producing deeper understandings and improving practice, it is essential that curiosity is fostered about teaching, learning, and curriculum in a context in which all participants/stakeholders (e.g., teachers, students, parents, school leaders) are considered as resources for doing research and benefiting from it.

Structures, including policies and practices at all levels of education, should afford high-quality teacher research – as a requirement, not just as a possibility that is condoned with restrictions on the use of tools such as digital technologies (e.g., video and audio recordings). Appropriate research methodologies used by teacher researchers include interpretive approaches that incorporate making sense of experience, learning from others' diverse perspectives, and testing interventions intended to improve practice. Teacher research is applicable in any institution where science education is practiced, having the goal of improving and sustaining high-quality learning environments.

Social life is complex and enacted practices (i.e., social interactions) are distributed throughout a collective with and without awareness. Since these interactions are basic units for learning, it seems desirable for all participants to become aware of key interaction patterns, contradictions to them, and data that are salient to teaching and learning. Seeking answers to the following broad questions expands awareness and provides opportunities for individuals and collectives to consider change: What is happening? Why is that happening? What contradictions are noteworthy? And what changes are desirable? Such questions can initiate and sustain ongoing programs of teacher research in which teachers and students regularly review answers to each of these questions and discuss those answers with others in a class. Not surprisingly, analysis of video and audio files of science lessons can lead to the identification of practices that should be used more often, those that might be improved, and others that could be used less frequently and perhaps be eliminated.

Cogenerative Dialogue

Cogenerative dialogue (i.e., cogen) is an activity in which participants from a class can discuss specific examples of questions like those posed above and their associated responses (Tobin and Llena 2011). The number of participants in cogen can vary from two to many – criteria for selection include shared experience of an activity such as a science lesson; differences in social categories such as achievement level, race, native language, and sex; and opportunities to participate actively and equitably. During cogen all participants have a chance to speak and be heard, and all contributions are carefully considered in regard to their feasibility and potential to improve the quality of teaching, learning, and goals. It is important to listen, build understanding of others' contributions, and fully consider their efficacy. Recollections and associated stories about what is happening are important resources for cogen and can lead to striking changes in the quality of the learning environment. Also, analyses of video and audio files are usually part of cogen. Changes deriving from cogen include expanded social networks, increased strength of social bonds, emergence of solidarity, and increased magnitude of positive emotions that transfer to the classroom. Because cogen provides all participants opportunities to speak and be heard, it is frequently part of a methodology for teacher research, affording salient questions to be asked and answered.

Science in Teacher Research

Becoming aware may be sufficient for initiating changes. For example, alerting participants to characteristics considered as likely to be salient to their learning allows them to reflect on their own practices in relation to those characteristics and make significant changes in the incidence of mindfulness in science and science teacher education classes, quality of dialogic inquiry, and intensity of positive emotions. Similarly, awareness about physiological variables provides new foci for teachers' and students' reflections and possible changes. In some of the most recent studies, finger pulse oximeters have been used to provide participants with a personal display of pulse rate and percentage of oxygen in the blood. Teachers often have a high pulse rates and oxygen levels fluctuate from a saturation level of 100 % to low levels beneath the percentage considered safe for jet pilots to fly a plane (i.e., <92 %). Oximeters, which provide three measures per second for pulse rate and oxygenation, enable teachers and students to create personal and collective landscapes for pulse rate and oxygenation, from which they can identify patterns and contradictions that are relevant to their well-being. Participants often want to change pulse rate and oxygenation to levels they find acceptable. For example, teachers might find a pulse rate of 138 beats per minute unacceptably high in a context of an average pulse rate of 90 and standard deviation of 10 beats per minute. Similarly they might be concerned about oxygenation levels below 90 %, especially if such levels are sustained for meaningful amounts of time (i.e., more than just a fraction of a second). A low-oxygen scenario usually raises questions about saturation, especially because the standard deviation of oxygenation data for a teacher might be less than 1 % – that is, a question that arises is whether oxygenation levels of 99–100 % are problematic. Concerns such as these raise questions about whether changes are needed and, if so, how they might be enacted. Accordingly, collaborating with teachers to design and enact interventions to potentially change pulse rate and oxygenation of the blood leads to very new forms of teacher research.

Based on research on physiological expression of emotions and breathing patterns, another approach has been to design a breathing meditation intervention to ameliorate emotions (Philippot et al. 2002). During 3-min intervals at the beginning and midway through a class, participants stopped what they were doing and focused on their breathing, expanding their abdomen on the in-breath and contracting their abdomen on the out-breath – letting go of emotions and thoughts as they occurred. In this way teachers and students used breathing meditation to focus and alleviate undesirable emotions as they arose. Notably many participants used breathing meditation to reduce stress in out-of-school contexts. These approaches put into practice science in teacher research in new and interesting ways.

Teacher research is considered an essential component of exemplary science teaching, having the purposes of ascertaining what is happening in science education at classroom and institutional levels and dialoguing with stakeholders such as students concerning how to improve and sustain appropriately high-quality learning environments. As a central part of an enacted curriculum, teacher research should not be regarded as optional or, even worse, a detriment to learning. As science curricula are enacted, the research-practice gap should be eliminated by research that orientates toward high-quality teaching and learning.

Conclusion

As is the case with most research on teaching and learning, teacher research is an activity that can be enriched through collaboration of stakeholders, including teachers, students, administrators, parents, and university science educators. What is learned can potentially reform science education writ large, and for that reason collaboration of a multi-institutional, multivoiced nature is regarded as highly desirable.

Cross-References

- ▶ Pedagogical Knowledge
- ▶ Project for Enhancing Effective Learning (PEEL)
- ▶ Self-Study of Teacher Education Practices (S-STEP)
- ▶ Teacher Educator as Learner

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Teacher Supply and Retention

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Keywords

Professional development; Teacher development; Teacher recruitment; Teacher shortage; Teaching force

Main Text

The single most important sector of school science education is the teaching force. However, in many countries, effective science teachers are in relatively short supply. European exceptions to this pattern include Finland, Spain, Scotland, and Northern Ireland (EURYDICE 2002). In some cases, recruitment of new teachers cannot keep up with the number of teachers changing careers or retiring (sometimes referred to as "wastage" as opposed to "turnover" which refers to people who take up a post at another school).

Science graduates have a range of skills which make them relatively highly employable. As such, many of the best graduates, particularly in the physical sciences, may never consider careers as a science teacher. Factors affecting their decisions may be related to the status of teaching in their specific society, the levels of remuneration in that society, a preference for working in a business or commercial environment, etc. In some countries, the prospect of having to teach across biology, chemistry, and physics (and, in some cases, earth science) may not appeal to graduates who see themselves as specialists in one science, although this appears to be very much less of an issue in those countries with long traditions of general or combined science courses – put simply, in those countries where general/combined science is the lived school experience of the graduates.

Many strategies have been used to increase recruitment. These include financial incentives ("golden hellos" or training bursaries), diversifying the available routes into the profession (so as to allow overseas and mature entrants to take up places), allowing unqualified people to teach, providing taster courses (opportunities to spend time in one or more schools prior to applying during or after undergraduate study), short-term appointments for leading graduates (such as the Teach First [England], Teach for America, Teaching Australia schemes), and booster courses to increase applicants' chances of surviving teacher training. It is also the case that teacher recruitment tends to increase when a country's economy is weak – teaching is seen as offering a secure if not particularly well-remunerated career.

Strategies aimed at improving teacher retention usually take into account the reasons why people leave the profession. Research – from England – across all subject areas suggests that among the main factors to influence teachers' decisions to leave the profession were workload (most important), the opportunity for a new challenge, the school situation, salary (least important), and personal circumstances (Smithers and Robinson 2003). A disproportionate number of leavers were either young, with a only few years' service, or much older and approaching retirement. Leavers tended to be female (often wanting to have a family and then return) and to come from the shortage subjects such as the sciences. Young leavers were more likely to cite salary and personal circumstances and less likely to complain of workload than the other leavers.

Strategies to reduce the numbers leaving the profession during initial teacher education or while they are in post include coaching, mentoring, appraisal, increasing opportunities for professional development, and financial incentives. Studies reporting on teachers' lives and careers tend to suggest that the quality of the school management and the level of support from fellow teachers are critical factors affecting how teachers feel about themselves and their work. A number of models of teacher development make reference to three or more dimensions of development including the personal, the social/school level, and the professional (knowledge, skills, etc.). Professional development aimed at increasing teacher satisfaction as well as effectiveness seems to work best when these factors are taken into account.

Cross-References

- ▶ Student Teachers' Needs and Concerns
- ▶ Teacher Professional Development

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Teachers' Understanding of Assessment

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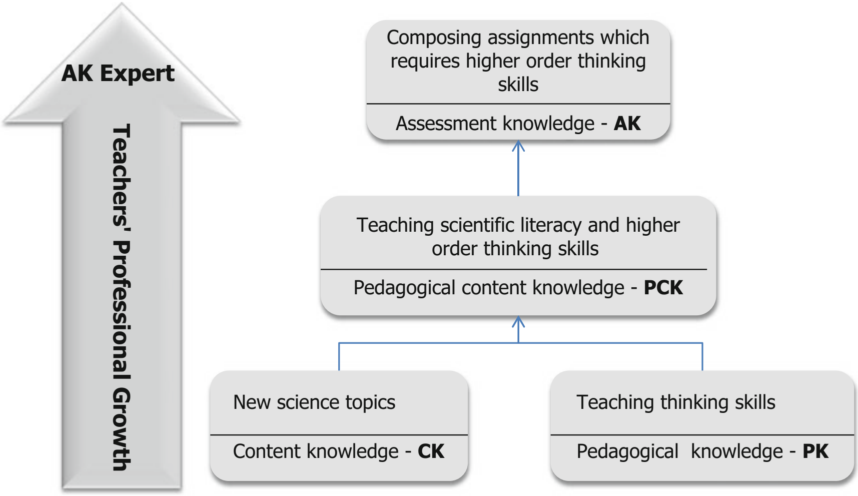
Keywords

Teachers' knowledge of methods of assessment

Teachers' assessment knowledge, AK, is the knowledge and understanding teachers have about assessment, its value, its types, and its applications for evaluating students' learning outcomes. Assessment carried out in the classroom is designed both to help teachers determine what and how well students learn (assessment of learning) and to improve students' learning (assessment for learning) (Birenbaum et al. 2006). These two possible objectives of assessment are also referred to as summative and formative assessment, respectively. Most of the students' assessment mode and content are determined by their science teachers – the assessment agents. They choose what, how, and when to assess their students. Since new and challenging reforms in science education require teachers to teach for meaningful learning, science teachers are required to cope with new teaching methods and assessment that are aligned with these new methods (Abell 2007; Magnusson et al. 1999).

Teachers in general and science teachers in particular are important players in successful implementations of new curricula. While developing their content knowledge (CK) and pedagogical content knowledge (PCK), teachers need training and ongoing support in adapting to new content, as well as new pedagogical and assessment methods. Pedagogical content knowledge, as defined by Shulman (1986), is "a particular form of content knowledge that embodies the aspects of content and of teaching ability" (p. 9). Shulman's theory is related to content knowledge, general pedagogical knowledge (PK), curriculum knowledge, pedagogical content knowledge, knowledge of learners and their characteristics, knowledge of educational contexts, and knowledge of educational purposes and values. However, Shulman's theory did not focus on teachers' assessment knowledge. Over the years, this theory has been revised and extended by science educators. Magnusson and colleagues (1999) and Abell (2007) proposed a comprehensive interpretation of pedagogical content knowledge that included science curriculum goals and materials, science learners, and aspects of assessment knowledge, such as science assessment methods. They suggested that experienced teachers should



Teachers' Understanding of Assessment, Fig. 1 Stages in teachers' professional growth while teaching and assessing higher order thinking skills

know what aspects need to be assessed in a particular setting and used the term "knowledge of methods of assessment" (Magnusson et al. 1999, p. 108).

There is a gap between high-stakes accountability tests and students' learning outcomes resulting from small-scale curricular and instructional practices. Examples of such high-stakes accountability tests are Trends in International Mathematics and Science Study (TIMSS) and Progress in International Reading Literacy Study (PIRLS). This gap underlines the importance of teachers' assessment knowledge. This is even more crucial in view of the difficulties most teachers face while attempting to apply the variety of assessment methods in order to achieve useful and efficient classroom and individual students' assessment and to enhance their instruction. Encouraging teachers to design and implement suitable assessment tasks can broaden teachers' knowledge about students' learning outcomes and may serve as a way for them to decide if they need to repeat teaching of specific subject matter or skills. We expect science teachers to develop assessment knowledge for measuring not only learning but also scientific and thinking skills. Teachers do not always feel sufficiently prepared to assess their students. These feelings of inadequate readiness are noticeable especially when the teachers are exposed to new curricula and teaching methods. Without teachers' effort to align assessment with the latest education reform requirements, their students will not develop the required scientific and thinking skills.

Teachers' knowledge about assessment of learning and assessment for learning is an essential part of teachers' knowledge in general and pedagogical content knowledge in particular, especially in an era of science education reforms. In the past, but in many places even today, the most common way of assessing students has been the traditional form of a summative test. This sort of test usually examines content knowledge, and it does not assess higher-order thinking skills. In recent years, researchers have shown that teachers who applied formative assessment in order to promote students' higher-order thinking skills in a context-based environment succeeded in developing the desirable skills. According to Dori (2003), assessment tasks should cover a broad spectrum of cognitive capabilities, including not only low- or intermediate-order thinking skills but also higher-order thinking skills. The latter include analyzing data, asking questions, solving analytical and conceptual problems, drawing conclusions, constructing models, moving across different representations, designing new experiments, and transferring knowledge from one scientific domain to another. In order for teachers to be able to assess their students' higher-order thinking skills, they need to synchronize between their teaching and their assessment while keeping in mind their content knowledge and pedagogical goals. Researchers showed that teachers' lack of assessment knowledge limited their pedagogical content knowledge. Teachers' assessment knowledge is knowledge at a higher level, above pedagogical knowledge, content knowledge, and pedagogical content knowledge (see Fig. 1 based on Avargil et al. 2012).

In order for teachers to develop assessments that will support their students in meeting the recent science education reform requirements and expectations, they first need to broaden the spectrum of their pedagogical content knowledge. Having gained a sufficient level of pedagogical content knowledge, science teachers can then design assessment tasks that are commensurate with the new teaching methods and apply them in their science classrooms. Engaging in designing and implementing a range of assessment activities will, in turn, expand the science teachers' assessment knowledge.

Assignments science teachers develop may serve as a tool for defining their professional growth and assessing whether they have made progress beyond the PCK level and attained the assessment knowledge level (Avargil et al. 2012). Observing science teachers as they instruct their students how to apply feedback to improve scientific literacy and higher-order thinking skills is another means for teacher mentors to determine whether these teachers reached a satisfactory level of assessment knowledge.

Cross-References

▶ Assessment: An Overview
▶ Embedded Assessment
▶ Pedagogical Content Knowledge

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Teaching and Learning Sequences

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In science education one notable line of inquiry, aspects of which date back to the 1980s, involves the design, implementation, and validation of short, topic-oriented sequences for science teaching in several subject areas, including, optics, motion, heat, electricity, structure of matter, fluids, respiration, and photosynthesis. This work falls within a science education research didactical tradition in which teaching and learning of conceptually rich topics are investigated at micro (e.g., single session) or medium (e.g., a few weeks) level rather than at the macro level of a whole curriculum (1 or more years). Although various terms have been employed in the past, the term teaching-learning sequence (TLS) is now widely used to denote the close linkage between proposed teaching and expected student learning as a distinguishing feature of such research-inspired subject-oriented sequences. A TLS is both an interventional research activity and a product, usually lasting a few weeks, comprising well-validated teaching-learning activities, empirically adapted to student reasoning and often including well-documented teaching suggestions and expected student reactions.

The state of the art of TLS in 2004 was described in a special issue of the International Journal of Science Education (Vol. 26, No. 5, edited by Méheut and Psillos). The editors noted that TLS is a flourishing research sector, with several valuable empirical studies in various topics published over the last 30 years and that both theoretical positions and questions or issues regarding the character of research into TLS have been brought to the attention of the European (and indeed the worldwide) science education research community. Researchers generally agree that this sort of activity involves the interweaving of design, development, and application of a teaching sequence in a cyclic evolutionary process enlightened by rich research data.

Interest in design research and development has also spread to education research more generally, mainly in the USA, under the broad perspective of design-based research (DBR) (Design-Based Research Collective 2003). DBR has been advocated as an approach to educational research that seeks to provide means for developing innovative teaching and learning environments and at the same time to develop theories of learning and teaching adapted to specific contexts. Few references to TLS appeared in early DBR studies and vice versa, however, a situation which has only recently started to change.

Examination of publications concerning TLS- or DBR-based work brings to the fore certain common features. First, the work is interventionist, seeking to develop useful products, such as teaching materials, in response to emerging problematic situations and needs. Second, it aims to contribute to the development of educational theory embedded in specific contexts in normal classrooms. Third, the work is iterative, which implies that both product and design are tested and revised in several cycles. Fourth, it is usually carried out by teams involving both researchers and teachers. These features also constitute open issues that continue to be studied and debated by researchers.

Work in any design process involves drawing on several kinds of knowledge, including grand theories relevant to the problem. In the case of TLS, various grand theories of pedagogy, development, learning, motivation, epistemology, history of the subject, and sociology of education are possible sources. Theories like social constructivism may afford general suggestions that can contribute to design principles but have little to offer in designing teaching on a specific topic or providing answers to questions such as “how to deal with students’ conceptual difficulties in explaining situation X” or “how to prompt students to relate scientific knowledge to evidence during experimentation on topic Y.” Accordingly, certain frames or models for the design and development of a TLS have been suggested and used by researchers as intermediates between grand theories and subject-oriented demands. These are presented below.

Starting from Freudenthal’s position, Lijnse (1995) and the Utrecht group proposed a frame for developing “didactical structures” within an approach they called “developmental research.” Great attention is paid to the motivational and meta-cognitive dimensions and to the learning on the part of the teachers made necessary by such an approach. Some general indications concerning conceptual development are given, with three suggested levels: selection of focus, transition to a descriptive level, and, if necessary, transition to a theoretical level. In this frame it is suggested that the teaching-learning process be deconstructed into five phases: motivation, question, investigation, application, and reflection. In the context of developmental research, didactical structures are empirically regulated and iteratively refined, starting from a scenario describing and justifying (a priori) the design of teaching-learning activities and the expected teaching-learning processes.

The model of “educational reconstruction” (MER) developed by Duit, Gropengießer, and

Kattmann attempts to combine the German hermeneutic tradition on scientific content with constructivist approaches to teaching and learning. MER holds that clarification of science subject matter is an important issue if instruction in a particular science content is to be developed and is based on an integrated constructivist view. On the one hand, the knowledge acquisition process is seen as an active individual construction process within a certain social and material setting, while science knowledge, on the other hand, is viewed as a tentative human construction. The analysis of content structure leads to constructing the core ("elementary") ideas of the content to be taught. Designers' initial ideas about the construction of instruction play an important role in planning empirical studies on teaching and learning. The results of empirical studies dynamically influence the processes of educational analysis of the content, the setting of detailed goals and objectives, and the construction of instruction.

The "Two Worlds" frame was developed by Tiberghien and the Lyons group, in order to inform the design of TLS by drawing on the epistemology of experimental sciences and on Vygotsky's theory of learning (Buty et al. 2004). In a series of studies, the authors make a double categorization of knowledge into everyday knowledge and physics knowledge, each offering ideas for describing objects/events in the material world which may be linked via modelling processes to distinctive theories/models for interpreting, predicting, or explaining events in the material world. Modelling is treated as a foundation for scientific knowledge, and the physics classroom is viewed as a place where students are invited to participate in an educational community where one of the teacher's roles is to convey some of the knowledge and methods of scientific communities. Two specific complementary design tools have been developed for informing the design mainly of physics teaching: the "Knowledge Distance" tool, which potentially guides the framing and sequencing of the teaching content, and the "Modeling Relations" tool, which may guide the design of specific teaching activities at a more detailed level.

The Leeds group (Leach and Scott 2002) draws upon Vygotskian grand theory on meaning-making. Approaches of personal sense-making and a realist ontology have been integrated with this Vygotskian theory to develop a social constructivist frame on learning scientific concepts. This brings together the social-interactive and personal-sense-making parts of the learning process and identifies language as the central form of mediation on both the social and the personal plane. It draws upon sociocultural approaches in conceptualizing learning in terms of developing a new social language and in identifying epistemological differences between social languages and upon evidence relating to alternative conceptions in clarifying the nature of the learning required by students in order to make personal interpretations of the social language of science. The "Learning Demand" is a design tool that was developed for identifying the conceptual aims of science teaching at a more detailed level. Another design tool, the "Communicative Approach," focuses on classroom discourse. The verbal communication in the classroom is described in terms of two dimensions: authoritative/dialogic and interactive/noninteractive.

Seeking to design an effective TLS that also advances educational theory related to a specific topic, Andersson and the Gothenburg group (Andersson and Bach 2005) adopt a somewhat different perspective. They suggest that design work which aims to build insights into conditions that favor learning with understanding may or should develop "content-oriented theory" for specific topics. Content-specific theories should focus on specific issues such as students' understandings, the nature of the topic, and general issues such as the key role of the teacher as an agent of education and culture. In addition TLS work should design and test "useful products," such as teachers' guides and study material for students, which may be put into practice in various ways. They consider that designers of a TLS may provide either a detailed sequence of activities and suggestions to teachers or some general principles as well as the relevant materials so that teachers themselves will develop relevant activities. The authors and their colleagues consider that science education should develop as an independent domain rather than a kind of applied psychology

Working with TLS involves the conceptualization and treatment of situations and interactions that may be complex and therefore the refinement of these sequences to ensure that their work is of specific importance. There is general agreement that a TLS normally develops gradually through a cyclic evolutionary process informed by research data. This process results in the enrichment of the TLS with empirically validated student outcomes and contextual applicability. Such a design and development process tends to be iterative. It involves successive approximations of a desirable intervention. Each iteration helps sharpen aims and deepen contextual insights and contributes to the outcome of design principles drafted, products improved, and professional development opportunities for the participating team. Analysis, design, and evaluation take place within each iteration. Analysis primarily features assessment of harmony (or discord) between the intended, implemented, and attained learning. Its findings usually offer guidelines for design that target the closure of one or more gaps between the intended, implemented, and attained curricula. These guidelines take the form of design specifications that will shape the products of teaching sequences. As development continues, products may be partially or even wholly elaborated. At the conclusion of a design cycle, a product's stage of development influences the kind of formative evaluation activities that may take place.

Work on TLS provides a fruitful recent advancement of science education research and development of empirically validated products. This said, it is recognized that designers' and researchers' craft knowledge about effective practices is valuable for providing contextually valid answers to specific didactical issues and questions. The advancement of the dialogue between grand theories, design frames, methods of empirical refinement, and participants' craft knowledge is also considered to open new perspectives in addressing both the features of the design process and the expected products for improving science teaching and learning.

Cross-References

- ▶ Constructivism
- ▶ Designed-Based Research
- ▶ Developmental Research
- ▶ Evidence-Informed Practice in Science Education
- ▶ Model of Educational Reconstruction
- ▶ Socio-Cultural Perspectives on Learning Science
- ▶ Transposition Didactique

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Teaching and Sociocultural Perspectives

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Keywords

Cultural influences; Science learning; Science teaching; Sociocultural perspectives

Background

The sociocultural dimension is an integral part of education systems, and classroom teaching and learning are neither culture- nor context-free. The learning of different subjects is bound to be affected to varying extents by the sociocultural backgrounds of learners and teachers, the political and sociocultural milieu, and the broader global education environment. Science education is no exception, despite the universal nature and empirical stance that are purported to be unique to science. The ideal vision of "science for all" implies that learning science and developing scientific literacy are a common entitlement of students, irrespective of their sociocultural background. However, a common consensus on what constitutes the aims, contents, and pedagogies of a "universal" science education has yet to be reached, and the ideal of equity of opportunity in learning science is far from a reality considering the uniformity of the learning materials, which is in stark contrast to the immense sociocultural diversity within and across various classroom settings. Readers may refer to the review articles by Cobern and Aikenhead (1998) and Lee and Luykx (2007) for an overview of how these perspectives impinge on the teaching of science. Three fundamental questions are pertinent when considering teaching and sociocultural perspectives and how the gaps in equality can possibly be bridged to achieve science for all:

1. What are the sociocultural perspectives that bear on the teaching and learning of science?
2. How are the teaching and learning of science influenced by these perspectives?
3. How can science teaching respond to the challenges posed by sociocultural perspectives? What is the meaning of sociocultural-sensitive teaching in achieving science for all in light of the sociocultural diversity among science students?

The Sociocultural Dimension with Respect to the Teaching and Learning of Science

If science education is regarded as a process of cultural transmission, like other areas of education, it will encounter obstacles when it meets with cultures that are at odds with or not in alignment with the culture of science. This transmission entails the crossing of cultural borders, particularly by non-Western students (Cobern and Aikenhead 1998). The literature reveals the interplay between a number of sociocultural factors, ranging from explicit factors such as socioeconomic status, language, schools, and the politico-economic milieu to more deep-seated ones such as traditions, religion, values, and worldviews, with globalization intertwining among all of these. Socioeconomic status and school factors influence students' chances of accessing the resources that are essential for achieving the goals of science education. The 2011 TIMSS study showed that schools with more resources had higher average student achievement than those that were under-resourced (Martin et al. 2012). It is not easy to pinpoint the exact reasons, but well-resourced schools are more likely to benefit from a higher-quality teaching staff, a technology-rich learning environment, and the support of laboratory facilities. However, the influence of the general socioeconomic climate on students' learning seems to work in a rather different way through influencing values at the regional or national level. The findings of the ROSE (Relevance of Science Education) project found, paradoxically, that the more developed the country, the less overall interest its young population seemed to have in school science. A possible inference is that children in developing countries see learning science in school as a privilege, whereas those in developed countries view it more as a duty or obligation, thereby affecting their motivation to learn science (Sjøberg and Schreiner 2010). The language environment in which science teaching and learning take place is another problematic issue. The use of English as the medium of instruction (MOI) due to the traditional dominance of Anglo or Euro-American culture in science and science education poses a barrier to learning, particularly in non-Western countries. Switching the MOI to the mother tongue cannot solve all of the problems, because difficulties abound in translating the culture-laden terminologies of science without distorting their meaning to a certain extent.

An example is the term "hypothesis," which is translated into Chinese as "assumption" rather than as "tentative explanation," thereby resulting in misconceptions on the part of the learner and even teachers and textbook writers.

Given these various influences on student learning, one would expect sociocultural factors to affect students to a greater extent than they do teachers, as the latter have already been acculturated in science. However, teachers are also liable to deep-seated politico-social influences that are manifested in different ways. Science teachers inevitably engage in power relationships with students, which may compromise the use of student-centered learning approaches. Teachers who adopt an authoritative stance in their relationships with students may be less inclined to use student-directed open inquiries or argumentation-oriented classroom discourse. This tendency is often exacerbated by the relatively large class sizes in less-developed countries, which make it difficult for the teacher to balance the need for classroom control and the desire to adopt a more open type of inquiry-based instruction to achieve important learning goals. Teachers are also under the influence of the mainstream values of the school, community, or society at large that may be at odds with their own beliefs or the goals of science education, thereby curtailing open discussion of some potentially controversial socio-scientific issues such as stem cell research or scientific theories such as evolution. These mainstream values are also likely to interact with students' own cultural values to influence their moral judgment and decision making on socio-scientific issues.

Responses to Address the Challenges from Sociocultural Contexts

In response to the problems associated with the sociocultural dimension of teaching and learning science, how can science teachers minimize the equity gap due to cultural diversity and help students to cross the cultural boundary, and how may they help students to view science and science learning in perspective while respecting the students' cultural diversity? It is perhaps instructive to identify the challenges faced by teachers before discussing potentially fruitful responses. Some of these challenges are outlined below:

1. To identify the disparity between students' cultural backgrounds and the culture of science and how the former may affect science learning
2. To be aware of the nature of teacher-student relationships and the school culture or ethos and their compatibility with the goals of science education
3. To reconcile scientific and nonscientific beliefs, e.g., religions, indigenous worldviews, and societal values that are deeply rooted in different cultures, while recognizing the important differences between the two
4. To be aware of the teacher's own thoughts and beliefs about the influence of sociocultural contexts on science teaching and learning
5. To provide a language-enhancing environment for non-English-speaking students while reducing the language barrier in science learning

Even with these daunting tasks to accomplish, sociocultural diversity need not be seen as a barrier to science learning. It could be perceived as an opportunity to encourage or challenge students to reflect on their own and other cultures in comparison with that of science. Through this reflection, they may come to a better understanding of the culture of science. To facilitate this reflective process, students should be made aware of the nature of science, including the subjectivity of scientific theories and their empirical and tentative nature, and contrast it with the underpinnings of their cultural or indigenous beliefs. For example, they could compare and contrast creationism with the Darwinian theory of evolution and indigenous medicine with modern health and medical science, leading to a personal view of the nature of the differences between science and their cultural beliefs and the unique contribution of both toward the construction of knowledge and society. Additionally, making use of students' everyday knowledge relevant to science practices and considering how science could extend their personal knowledge base may facilitate students in crossing the border between their own culture and the culture of science. Furthermore, non-English speakers could be engaged in inquiry-based learning that provides a language-enhancing environment to help them learn both science and language in a meaningful and synergistic way. However, responding to sociocultural diversity does not mean that teachers should undermine science or uphold scientism. On the contrary, teachers should communicate vividly to students how the substantial contribution of science to society was made possible by the use of creative thinking, scientific reasoning, and evidence-based argumentation and judgment driven by scientific attitudes, the integration of which has made science distinctive from other knowledge systems. As students' perspectives on socio-scientific issues are likely to be influenced by sociocultural or contextual settings, engaging different student groups in cross-cultural or cross-contextual exchanges on global or regional issues could extend their capacity for multi-perspective reasoning and metacognitive reflection, which are essential for consensus building and problem resolution in an increasingly connected and globalized world (Lee and Grace 2012).

Future Directions

A culture-sensitive science curriculum needs to be implemented to promote equity in science learning. Science educators and researchers should explore the meaning of such a curriculum and how it could be manifested in light of the nuanced sociocultural diversity within and among various student groups and the subtle influences of school policies, community values, and the politico-economic milieu. The literature shows that teachers can be empowered to turn the challenges of students' cultural diversity to their advantage by understanding and accommodating sociocultural differences, using students' everyday cultural experiences relevant to science, and facilitating intercultural understanding and exchanges. A future agenda for science educators and researchers should involve rethinking the meaning of "teaching science for all" from different sociocultural perspectives and how it could be incorporated into effective classroom practice.

Cross-References

- ▶ Borders/Border Crossing
- ▶ Culture and Science Learning
- ▶ Cultural Influences on Science Education
- ▶ Cultural Values and Science Education
- ▶ Socio-cultural Perspectives and Characteristics
- ▶ Socioscientific Issues

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Teaching for Conceptual Change

▶ Conceptual Change in Learning

Teaching in Play-Based Contexts

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For some lay observers, play is mistakenly viewed as a leisure and uncomplicated activity done by young children. Lay observers may also see early childhood play-based settings as lacking academic opportunities for young children and may regrettably view the role of teachers in early childhood play-based contexts as simply custodial managers of chaos. However, a play-based context sets a stage for meaningful exchanges of thought that can beneficially challenge children's understandings and be particularly suitable for transforming children's everyday understandings to scientific knowledge.

While there have been shifts in theoretical approaches and differing texts on how one may view young children engaging in the human venture of science, early childhood play-based environments are settings for scientific inquiry, which can engender even the youngest of children to be critical thinkers, problem solvers, and reflectors of reason.

Play as a Context for Learning About the World

The concept of play is viewed as an essential means for a child to both explore and gain a better understanding of the world around them. When children play, it allows them to challenge their preconceptions, engage in safe risk taking, and encourage imaginative experimentation. Play can involve deep engagement about how and why things happen, as well as provide the driving force for experimentation and exploration. The companion to play is learning. Play is intertwined with learning, as it has been shown to bring elements of enjoyment and focus to learning experiences within play-based settings.

While the concept of play has been a key area of focus in early childhood education research, there is no firmly agreed-upon standard definition of the concept of play. Instead one's theoretical approach to children's learning appears to be the means through which the concept of play is described. For instance, a theoretical belief that situates play as an innate activity for making sense of the world would agree with Piaget's view that "play is the child's way of adapting to his or her situation in life, assimilating it and understanding it" (Ebbeck and Waniganayake 2010, p. 11). This view would see play as an intrinsic means for children developing representations of the world through a series of stages. However, a theoretical view that sees intellectual development coming about through social dialogues within specific context may align with Vygotsky's view that play leads development by lending "a space for the conscious realizations of concepts" (Fleer et al. 2009, p. 4). In brief, this view sees social interactions as providing the space for children to shift their understandings and that through play, young children can bring their everyday understandings of their world and use these to form foundations for higher-order thinking and learn scientific concepts. Vygotsky described children involved in play as thinking a "head taller" than their actual existence. Thus, the context of play provides space for "head taller" scientific concept learning. While there are other perspectives relating play and learning, most draw heavily on Vygotsky and Piaget's perspectives (Ebbeck and Waniganayake 2010).

There are different types of play that support learning, for example, those within social spaces, guided play (children engaged in pleasurable, spontaneous activities guided by adults which strongly support children's academic and social learning), object play (playing with toys and other objects which can lend insight into language and cognitive development of children with special needs), storytelling and fantasy, and play as performance. Despite the diversity in how children play and the differing theoretical perspectives on play, it is commonly agreed that with play comes opportunities for children to learn. More specifically, these diverse forms of play bring about varied opportunities for children to transform their understandings. Early childhood settings subscribing to play-based learning open the doors for children's everyday knowledge to be solidified and extended.

Play as an Act of Inquiry

Youngquist and Pataray-Ching (2004) argue that play associated with learning should be described as "acts of inquiry" rather than just "play." They contend that substituting the words "acts of inquiry" with the term "play" can bring about a new discourse that elevates the concept of play "as educational, meaningful, theoretically driven, and curricularly worthwhile in the academic setting" (p. 171). There is extensive research stressing the deeply intricate nature of play as well as proponents of play advocating for society as a whole to understand the fundamental importance of play, yet play is still often perceived outside the field of early childhood education as simple and devoid of academic rigor. Youngquist and Pataray-Ching (2004) suggest that talking about play as acts of inquiry allows play to be seen as it truly is – activities that entail complex critical thinking and reflection engendering new conceptual understandings.

When play is seen as an act of inquiry, young children can take a leading role in developing their own "action-ed" knowledge that is unique, meaningful, and co-constructed within the play-based learning context. Much like play, children learning about science can also be seen as engaging in acts of inquiry, as it entails children exploring and recognizing the science embedded within their everyday experiences.

Science as an Act of Inquiry

Real science begins with childhood curiosity, which leads to discovery and exploration. Babies engage in science through acts of inquiry, as they are born curious and interested in learning about their immediate environment. They use their senses for inquiry and depend on vision, touch, smell, sound, and taste in identifying the world in which they live. Infants explore and gain an understanding of physical and spatial concepts as they move around their environment by crawling, learning to stand independently, and mastering how to walk on different surfaces. At this point, they begin to interact more readily with the physical world and discover spatial awareness.

Toddlers can be viewed as little scientists. They are driven by great curiosity to explore the unknown. As 2-year-olds, they like to sort objects and put things into piles based on color, size, shape, or use. They enjoy filling and dumping experiences such as pouring sand and water into containers of different sizes. As children enter preschool or kindergarten, exploration continues. This time however, children begin to apply basic concepts to collect and organize information and answer questions. Preschoolers are naturally curious, often posing the question "why." Their desire to question, hypothesize, explore, and investigate is part of their very being. Young children's inherent sense of inquiry provides the foundation for scientific knowledge (Charlesworth and Lind 2013). This scientific knowledge is not science as a collection of facts, but instead looking at science as a means of dealing with and extending our everyday experiences.

Educators in the early years should endeavor to nurture, enrich, and sustain children's interest in scientific knowledge. Children's science experiences can be facilitated through the use of learning spaces that encourage children to observe, research, create, test hypotheses, and collaborate to find understanding (Campbell and Jobling 2012). Strategies for building upon children's everyday knowledge and leading them toward scientific understanding can also include the use of puppetry as well as the use of children's drawings paired with interviews about their understandings of particular occurrences. Early childhood educators can encourage both play and science by providing an abundance of materials that would allow children to measure, observe, weigh, and record the outcome of their play experiments. These catalysts to scientific thinking mesh well within play-based contexts. For young children, play and science are acts of inquiry on the world around them. The enthusiastic wonder with which children approach the world should be acknowledged and accounted for in early childhood programs.

Conclusion

Play is the platform for learning. It provides children with the space to be hands on, minds on, and action oriented (Campbell and Jobling 2012). Science is what children do and how they think about what they do. Science within play allows children to investigate, experiment, test, hypothesize, discover, and construct their own ideas, all of which enhance and build children's knowledge. Hence, science falls naturally within a play-based context, as it enhances and builds children's knowledge.

Cross-References

- ▶ ICT in Play-Based Contexts
- ▶ Learning in Play-Based Environments
- ▶ Scaffolding Learning

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Teaching Science Out-of-Field

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Keywords

Misassignment of teacher; Nonspecialist teachers; Outside of an area of expertise; Teaching out of area

What Is Teaching Out-of-Field?

In 1990, "teaching out-of-field" was described as "education's dirty little secret." The label "out-of-field" has been used since the early 1980s to refer to qualified (or certified) teachers (usually) teaching a subject for which they have no formal qualification. While the term "teaching out-of-field" is used in the literature, it is still a relatively contemporary and contentious label that is not widely adopted by practitioners. The term is more commonly associated with secondary school teachers (or middle school or high school, typically students aged 12–18 years).

Generally, a teacher is considered "in-field" if they possess a minor or a major and a teaching qualification (including a teaching method) in that subject. However, internationally, no universal definition for a suitably qualified teacher exists because of differences in teacher education, accreditation requirements variation in school systems, and state certification processes. Consequently, there is no common understanding of what might be considered out-of-field. The issue is complicated further for teachers of science because, in some countries, science is taught at the junior secondary level (ages 12–15) as a generalist subject, encompassing the main science disciplines. Therefore, even teachers who are technically in-field in "general science" can experience problems associated with out-of-field teaching, such as when teaching physics with only a biology background.

Incidence and Reasons for Out-of-Field Teaching

Out-of-field teaching arises for a number of reasons, such as unmet teacher demand, poor school leadership and management, teacher choice, and alterative curriculum models where teachers teach in cross-disciplinary teams.

Ingersoll (2002) places at the heart of the issue, at least in US schools, not supply/demand imbalances and inadequate initial teacher education, but "the manner in which schools are organized and teachers are employed and utilized" (p. 24). Internationally, the OECD raise the equity issue, reporting that teacher shortage problems seem to be most acute in schools serving disadvantaged or isolated communities. Other studies examining the Australian science (and mathematics) teaching workforce indicate that the incidence of teaching mathematics or science out-of-field has been a long-standing issue in schools and thus is a constant reality facing policy makers and school leadership.

In Australia, various state and national surveys of the teaching workforce have identified that between 16 % and 20 % of teachers of junior science (years 12–15) lacked a minor in any university science discipline (see a discussion on this in Hobbs 2013a). Similar figures are being reported from Korea and South Africa, with much larger figures reported in the USA (see, e.g., Ingersoll 2002). Out-of-field teaching appears to be most widespread at the junior secondary levels compared to the senior years where teachers tend to be more correctly assigned.

Ingersoll (1998) raised concerns that the extent of teacher shortages is masked when underqualified teachers fill these positions, thus resulting in an unrealistic picture of the shortage of science teachers being reported worldwide. The reality is that many schools experience difficulty recruiting qualified teaching staff, and the problem is exacerbated by the aging staff profile, uncertainty about career pathways, and poor teacher retention partly as a result of job dissatisfaction. Ingersoll (2002) argues that top-down styles of school leadership that make decisions based on budgetary constraints rather than what is needed by the faculty have contributed significantly to the high proportion of out-of-field teachers in the USA.

Implications for Teaching and Learning

Out-of-field teaching places additional strain on subject coordinators and school administrators due to the extra support, mentoring, and resources required. In turn, school leadership that does not acknowledge the complexity of teaching out-of-field and the individual needs of the out-of-field teacher can have disastrous consequences for teachers, particularly novice (also called early career or beginning) teachers.

For the teacher, being technically out-of-field does not mean necessarily that he or she will not be an effective teacher. However, highly effective teachers have a deep understanding of the subjects they teach, they encourage the study of their subject, and value the surface and deep aspects of their subject. The question as to whether an out-of-field teacher has these subject commitments and depth of knowledge without the required disciplinary and methods background must remain central when decisions are made about who is teaching what.

Research often identifies a lack of content knowledge and pedagogical content knowledge as being the key issue for teachers (see, e.g., Wallace and Louden 2002). In Wallace and Louden's review of some of the research from the late 1980s and 1990s, they identify the following issues for out-of-field science teachers:

- Lacking a "repertoire of pedagogical content knowledge tricks" (p. 27), including the representations associated with the content and the learning difficulties and strategies for overcoming them
- Lacking a knowledge of timing of activities used within a lesson
- Activities that are used without certainty of whether they will work and how they relate to the concepts
- Use of less "risky" activities

- Rapid and frequent changes to lessons
- Inadequate explanations leading to teacher and student confusion
- Common reliance on traditional teacher-centered methods, such as reliance on the textbook
- Limited confidence to discern whether students have understood the content

Research has also found that teaching out-of-field can compromise "teaching competence"; can disrupt a teacher's identity, self-efficacy (see, e.g., Hobbs 2013a), and well-being; and is often associated with teacher strain and attrition (Ingersoll 2002).

Many factors can determine whether a teacher "feels" out-of-field, regardless of whether they are technically in-field or out-of-field (Hobbs 2013a), factors relating to personal resources of the teacher (such as knowledge, background, commitment, and adaptive expertise); their context, such as the administration practices of the school, constraints, and affordances associated with the geographical region, school size, teacher supply and demand, and policy climate; and the availability of support.

Novice teachers are often assigned out-of-field. They may be appointed to a position at the school on the proviso that they accept an out-of-field load, or as the least senior teacher in the school, they may be expected to "fill the gaps" at the junior secondary level. Unfortunately, novice teachers also have the highest attrition rates, particularly in the USA (Ingersoll 2002). Research is showing that beginning teachers are at greatest risk when teaching out-of-field because they have a limited knowledge base. Novice and experienced teachers respond differently to teaching out-of-field, with the more experienced teachers utilizing to their advantage their solid base of general pedagogical knowledge (Wallace and Louden 2002). "Through the authority of their experience, they have a meta-awareness of what needs to be done to teach well, and the limitations on teaching imposed by their lack of knowledge" (Wallace and Louden 2002, p. 218). In addition, Hobbs (2013b) has shown that the discontinuity (disruption to practice and identity) experienced by some mid- to late-career teachers who take on an out-of-field subject can lead to more directed and focused learning as they are more able to reflect on and distinguish between the practices they are moving from and into. Novice teachers, however, can lack knowledge in many areas of teaching, so crossing the boundary from an in-field to an out-of-field space simply adds to the already enormous load and is less likely to produce learning gains in the same way as it might for experienced teachers.

The effect of out-of-field teaching on student achievement, engagement, and attitude toward science has been the focus of some research, although the data is not necessarily consistent. Little research shows that a science-qualified teacher at the lower secondary level increases student achievement. Furthermore, there is no research that shows that a science-specialist teacher will ensure students are more engaged, although there is a plethora of research that indicates that teachers who are passionate about their subject, and students engaging with the subject, are preferred by students.

Teacher Learning

Table 1 provides a range of support mechanisms that teachers can draw on in their learning. The nature of support needed by out-of-field science teachers depends on where the difficulties arise for teachers, such as lacking content knowledge, poor management of students in the laboratory, or inability to link activities to content. It is through identifying discontinuities that teachers may be prompted to reflect, innovate, adapt, learn, and develop new or expanding identities. Because discontinuity is individually determined, one size fits all approaches to professional learning are inappropriate.

Whether a teacher seeks out or undertakes professional learning for an out-of-field subject depends partly on their orientation to that subject, such as whether they see themselves as simply filling in for someone, making the most of an

Teaching Science Out-of-Field, Table 1 Support mechanisms used by out-of-field teachers

Support provision	Sought support	Constructed resources
1. Support materials (a) Curriculum and syllabus documents (b) Provision of materials (c) Textbook 2. Processes and people (a) Strong direction, leadership (b) Reduced allocation (c) Meetings (d) Team teaching (e) Observing others (f) Formalized induction (g) Mentors (h) Access to principal (i) PD in-service (school initiative) (j) Coach	3. Professional development (a) PD external (school or self-motivated) (b) Further study, retraining 4. Collegial sharing and discourse (a) Sharing of resources (b) Discussion of concepts and teaching ideas (expert others) (c) Mentors (e) Interschool links, networking 5. External support (a) Family and friends (b) Community resources	6. Personal experiences (a) Collecting examples and stories relevant to the topic (b) Interests informing curriculum development 7. Personal research (a) Mastery of concepts (c) Collecting resources (d) Construction of resources

Reported in Hobbs 2013a, originally reported in Darby, 2010

opportunity by endeavoring to maintain high levels of student engagement and achievement, or pursuing an interest because they have a high level of self-efficacy arising from positive historical interactions with the subject (Hobbs 2013a). Also, school leadership plays a strong role in supporting teacher development. Being aware of a teacher's area of need is important for school leadership to target their approach, such as providing out-of-field teachers with extra time for preparation and to work with subject-specialist mentors in the school area. Providing multiple opportunities to teach the subject can lead to a sense of success (Wallace and Louden 2002).

What Needs to Be Done

In light of the expected longevity of this issue, further understanding of its effect on all key stakeholders will inform appropriate local and systemic responses.

There are a number of ways that the problem of out-of-field teaching can be dealt with. Actions can be linked to three aims:

1. Reducing the need for out-of-field teaching
2. Improving the quality of out-of-field teachers
3. Increasing teacher readiness of teacher graduates

If the aim is to have enough qualified teachers, increasing the supply of science teachers is imperative. This may be done through governmentally supported initiatives to promote career change of professional in the sciences or to encourage recent science graduates to enter teaching. Yet another approach is for school leadership and management to ensure that adequately trained teachers are hired, allocated, and resourced.

If the aim is to improve teacher quality, then attending to the professional learning of out-of-field teachers is paramount. At both the school and the policy levels, there needs to be greater support for the retraining of out-of-field teachers so that they can be given the funding, time, and space to understand new and emerging teaching approaches. At the school level, conversations can be had with the teacher about subject allocation and the degree of support available and required.

If the aim is to ensure that teachers are adequately prepared for the reality of teaching, then some responsibility falls on teacher education programs to prepare adaptable and flexible teachers. Preservice teachers can be prewarned of the likelihood of teaching out-of-field, the skills, knowledge, and attitudes needed to be adaptable and flexible, and the variety of support mechanisms that can be provided, sought out, or constructed by them. Focusing on the development of resilience in preservice teachers may help them to accommodate new and different ways of thinking;

challenge their own beliefs, assumptions, values, and practices when faced with the dilemmas and tensions of teaching; and help them to employ proactive coping strategies.

Cross-References

- ▶ Identity
- ▶ Pedagogical Content Knowledge
- ▶ Primary/Elementary Science Teacher Education
- ▶ Science Teachers' Professional Knowledge
- ▶ Secondary Science Teacher Education
- ▶ Teacher Supply and Retention

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Team Teaching

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Background

Team teaching is a term used to describe a collaborative approach to teaching and learning. Co-teaching, collegial teaching, cooperative teaching, and complementary instruction are but a few of the terms that are encountered when reviewing the literature related to team teaching. Much of the literature describes team teaching in a similar way to Buckley (2000) who viewed team teaching as involving a group of instructors working purposefully, regularly, and cooperatively to help a group of students learn (p. 4). Buckley's purpose was to shift teachers away from working as individuals in isolation and move them toward working purposefully in collegial teams with common objectives. Thus, the need to create a team seems important. Bess (2000) described teams as "a group of experts . . . continually engaged with one another, their institution and with their clients . . . they bring knowledge into the group, they learn from one another and they learn from the students they teach" (p. 209).

Team Teaching in Teacher Education

Bess's notion of team, in particular the ideas of continual engagement and learning with each other and students, formed the basis of the successful team teaching approach described in the work of Keast and Cooper (2012). They identified a number of benefits of team teaching in science teacher education including greater freedom to make decisions in the moment than when teaching alone, greater confidence to be more flexible with approaches to teaching, easier to take risks during teaching, providing a different perspective on the same teachable moment, encouraging analysis of critical incidents in the moment from a knowledgeable outsider's perspective, and the opportunity to monitor teaching and change the direction of the experience from outside rather than within the teaching.

They found that team teaching made explicit their pedagogical reasoning more often which helped their preservice teachers better understand the decisions their teachers were making as they were teaching (Keast and Cooper 2012). In many ways, this approach to team teaching opened up new opportunities for these teacher educators to more formally develop their pedagogy of teacher education and to model teaching in ways that challenged more superficial views of modeling as mimicry.

Cross-References

- ▶ Modeling Teaching
- ▶ Pedagogical Knowledge
- ▶ Pedagogy of Teacher Education

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Technology Education and Science Education

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Keywords

Technology and Science Education Research

This entry considers possible interactions between technology education and science education.

Although often perceived as being strongly related, technology and science draw on different knowledges and practices and at their core represent different ways of knowing. It is therefore important that a broad education reflects both the interrelatedness of and the differences between technology education and science education. In explicating the implications for compulsory education, we explore the existence of technology education as a discrete school subject, as well as its introduction and integration into the science curriculum. We then compare and contrast the nature of science with the nature of technology. Our argument throughout is that embedding a broadly defined notion of technology in science education has the potential to enhance students' scientific *and* technological literacy. However, this potential has yet to be fully implemented and realized.

While there is no doubt that we live in an increasingly technological world, it can be argued that human endeavor has always been essentially technological and that technology today is just an accumulation of that activity rather than something new and unique. Even sophisticated information and communication technologies build from previous technological developments. However, the rapidity with which technological change is occurring in contemporary society is unprecedented – and will by all accounts continue to escalate. As a result, there is an increasing need for formal education to equip students for a world that is rapidly changing. Both science education and technology education have central roles in addressing this need, each having unique and important contributions to make.

Worldwide, science education and technology education generally sit as two discrete learning areas within school curricula. This is largely premised on understandings of the differences between science and technology as distinct disciplines. For example, whereas science is primarily focused on providing coherent frameworks to understand and predict the physical and natural world, technology represents an intervening in the world to develop products and systems that address human-identified needs and opportunities. "Technology education," therefore, means far more than "information and communication technology" or computing skills. Technology education also differs from technology in education.

Technological endeavors encompass a wide range of activities, including the transformation of energy, materials, and information in products, systems, and environments. Just as the different disciplines in science differ in terms of knowledge, content, and processes, so do the different disciplines in technology. For example, the knowledge and work of an industrial technologist differs substantially from that of a biotechnologist. This highlights the need for thinking about "technologies" rather than technology as a single endeavor. Schools often reflect different technologies by packaging them into discrete subjects, for example, materials technology, food technology, and electronics.

Within national and state curriculum documents, contemporary technology education often represents a broadening of more traditional gendered skills and craft-based subjects. While skills development has remained a core part of this expanded curriculum trend, concepts associated with the nature and process of technological endeavor have been introduced with far greater prominence than before, and aspects such as design have become increasingly important.

While technology education has been expanding its brief, science curricula, too, have been broadened internationally. A widespread change has been to include greater emphasis on technological applications of scientific principles. This reform has been driven by the view that science is a foundational subject for technological development and was spurred on by postwar education and economic policy in the 1940s and 1950s and, in Western industrialized countries, the USSR's initial forays into space. There was also growing recognition that contextualizing students' scientific learning using technological applications has potential to increase student engagement and enhance their conceptual understanding.

Science, technology, and society (▶ STS) curriculum initiatives, pioneered in the 1970s, reflected "science for citizenship" and "science for all" agendas and offered tantalizing opportunities for more integrated approaches to science education and technology education. In the majority of cases, however, the emphasis in classroom practice has remained on science, with the social relevance of technology valued far more highly than concepts associated with the nature of technology. Similarly, policy initiatives around the science, technology, engineering, and math (▶ STEM) movement, underpinned largely by political rhetoric situating future scientists as key to economic advancement, have in reality resulted in continued emphasis on science and mathematics, with a lesser focus on technology and engineering. Even with the inclusion in science curricula of socioscientific issues (▶ SSI), where the issue is often associated with a technological outcome of science (e.g., genetic modification of organisms for enhanced crop yield), scientific knowledge and ethical dimensions tend to be prioritized over technological aspects. However, it is sometimes the broader technological context that needs to be considered in order for a full understanding of the ethical issues to be developed. For example, the outcomes that can be achieved in a strictly controlled laboratory environment often do not reflect the reality of full commercialization. By ignoring this aspect, the complexity of developing commercial products is underplayed, obscuring the wider knowledge base required for full product development and perhaps reinforcing an erroneous notion of science and technology as being both simple and value-free.

In the majority of science curriculum innovations, therefore, technological examples or contexts have been an add-on rather than being more fully integrated. While examples of genuine curriculum integration do exist (e.g., Rennie et al. 2012), these are far less common, and content is relatively open to debate. It is also not yet clear what authentic assessment of these integrated units might look like.

Where science education continues to be prioritized over technology education, a common reason relates to the historical privileging of science as an intellectual pursuit with higher social status when compared with the learning of technical or craft skills, which is viewed as less academic and has traditionally been linked with lower socioeconomic positioning. The result is a valuing of science over technology at the school level as well as by society more generally. Second, it is often left up to science teachers to implement initiatives such as STS and STEM, and so the science subculture within which the teacher is embedded influences how these innovations play out in the classroom. In particular, the strength of teachers' science understanding and skills when compared with their technological knowledge/skills often means that science learning is privileged over technology learning and so predominates.

To take a more integrated approach to science and technology education in order to enhance students' scientific *and* technological literacy requires the teacher to have robust understandings of both the nature of science and the nature of technology. The development of this understanding is not unproblematic. In particular, teacher practices have strong links with their initiation and socialization into particular subject subcultural settings. This often leads to a consensual view about the nature of the subject, the way it should be taught, the role of the teacher, and what might be expected of the student. If technology is being increasingly linked with science as an area of study, then it is important that we understand both science teachers' perceptions of technology and the ways that these might influence the incorporation of technology into science classrooms. There are also concerning indications that even when science teachers develop broader views of technology, they may revert to their previously held notions (e.g., of technology as applied science) when faced with disparities between their new views and their practice, or when entering areas of uncertainty (Jones 2012).

A further challenge to integrating science and technology education relates to students' understandings of each of these disciplines. For example, narrow concepts of technology among students can affect student's learning of technological concepts. Further, students' existing concepts may have greater impact on their technological practice than their teachers, and these existing concepts can be difficult to change. This can be particularly challenging where teachers' own concepts of technology are fragile. In addition, many of the STS and STEM exemplars available appear to prioritize scientific knowledge over technological knowledge and skills (Jones 2009).

While science and technology both influence the way we see the world, they do so in different ways. For example, science has a cognitive motive aimed at understanding the world, whereas technology has a practical motive, focusing on what could or should be rather than what is (Vérillon 2009). Another distinguishing element between the nature of science and the nature of technology relates to the emphasis on design in technology, as opposed to investigating in science – means-ends reasoning as opposed to cause-effect reasoning (de Vries 2009).

Unlike scientific knowledge, technological knowledge requires a normative dimension. In other words, technological solutions are based on human judgements and the pursuit of the best outcome in terms of human preferences, rather than the most accurate outcome in terms of empirical evidence. Whereas a scientist might seek to understand under what conditions water boils, a technologist investigates, for example, ways to boil water with the minimum energy input. In addition, technological solutions tend to deal with multiple physical, environmental, and social variables, resulting in outcomes that might be suitable only within their intended context. In contrast, the development of scientific knowledge proceeds by isolating variables and reducing environmental complexity, leading to theories and laws that are highly substantiated. Further, technological pursuits often involve a valuing of certain variables above others. For example, in the design and construction of a vehicle, consideration is given to reducing friction when motion is sought but maximizing friction during braking. Therefore, technological solutions depend on the desired outcome for each particular situation. This example highlights that the outcome of technological intervention is pragmatic knowledge and the production of artifacts (Vérillon 2009). In contrast, the purpose of a scientific investigation is the production of descriptive and explanatory knowledge.

Often, it is how scientific knowledge is applied that is of interest and relevance to students. Technological developments therefore have much to offer science education in terms of engaging students and demonstrating the relevance of the science content. However, using technological applications only to exemplify scientific concepts has potential to reinforce the notion that scientific knowledge leads to technological development – "technology as applied science." This could be through science enabling technology, science being a forerunner to technology, or science being a knowledge resource for technology (de Vries 2001). However, such a view precludes understanding of other relationships between science and technology, including both technological developments preceding scientific discovery (common historically, e.g., many of Thomas Edison's inventions) and technological developments enabling scientific discoveries (also common historically, e.g., microscopes).

In ignoring these additional interrelationships between science and technology, there is the risk of simplifying the complex knowledge bases needed for both understanding and developing new technologies. In other words, science is only part of the equation in many technological developments – and it is these technological developments that are associated with addressing many of the world's social, economic, and environmental challenges.

Understanding science and technology as different, but often related in a range of ways in different contexts, is therefore important for students. This is particularly true given the increasing iterative interactions between scientific and technological knowledge in many contemporary developments. For example, pharmacology offers a rich repository of scenarios where both scientific and technological knowledge are needed. The development of mobile communication devices, with increased miniaturization and sophistication, similarly highlights the multiple interacting influences of scientific and technological knowledge.

Clearly, teachers need to consider the similarities and differences between the nature of science and technology in order that they have an appropriately broad understanding of each. This will help them firstly to evaluate the appropriateness of incorporating specific examples of technological applications into science education programs for particular purposes and secondly to work toward enhancing the scientific and technological literacy of students.

The need for both scientific and technological literacy is being increasingly recognized by science education research, with major science education journals publishing special issues focusing on technology education, for example, *Journal of Research in Science Teaching* (*2001*) and *Research in Science Education* (*2001*). Within the first of these publications, Cajas (2001) specifically recommends that scientific literacy includes a better understanding of technology.

Enhancing students' understandings of the nature of technology in conjunction with the nature of science is important for both their future citizenship, as argued above, and for broadening career opportunities. While historically there may have been a strong separation between science and technology careers, there is now an increasing number of employment opportunities where science and technology come together in some form. For example, science funding increasingly focuses on the interaction of the scientific discoveries with technological development and end-user applications.

To conclude, current science education has a relatively well-established tradition of using technological applications and technological problem solving to contextualize science learning. While having the potential to enhance student engagement and learning, such use of technological examples to contextualize science teaching and learning is not likely to lead to better student understanding of either the specific technology or the nature of technology more broadly. There needs, therefore, to be clarity about the purpose of using the technological context and what it does – and does not – offers to student learning. If there is the desire to maximize opportunities to develop students' technological literacy as part of their science education, the relationships between science education and technology education need further exploration – by policy makers, curriculum developers, education researchers, and teachers.

Cross-References

- ▶ Science, Technology, Engineering, and Maths (STEM)
- ▶ Science, Technology and Society (STS)
- ▶ Socioscientific Issues

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Technology for Informal and Out-of-School Learning of Science

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Keywords

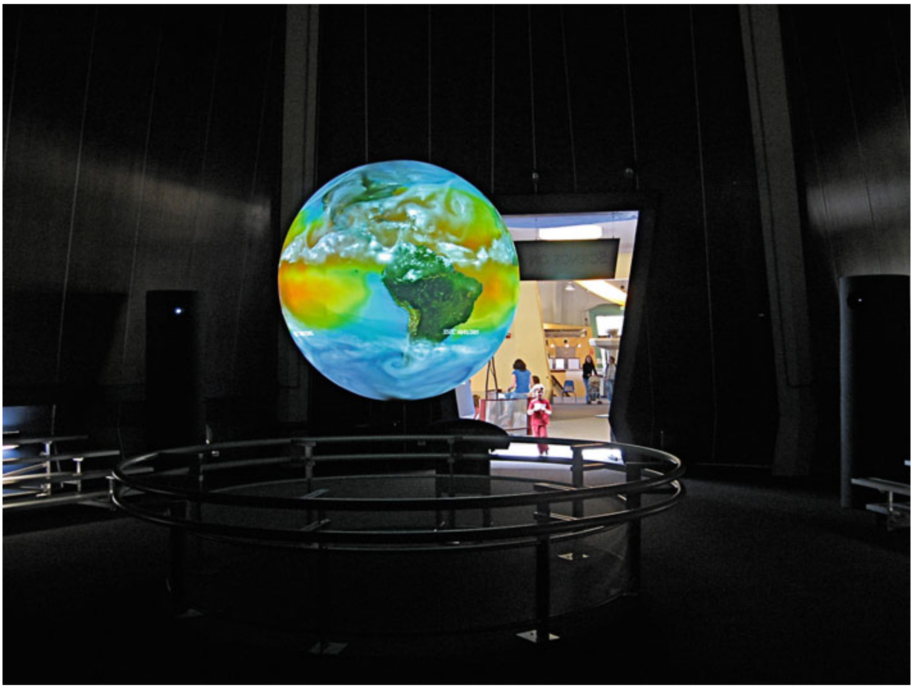
Citizen science; Informal learning; Museum learning

Learning that is supported in out-of-school settings is often referred to as informal learning, casual learning, extended learning, or free-choice learning. The learner voluntarily participates in activities, with his or her level of engagement growing out of curiosity or engagement in a social group or community. In contrast to formal schooling, informal learning has the characteristics of being fluid in activity and interactions, multigenerational, and even friendship-driven. The learner is often in charge of selecting the activities, location, and co-participants in the learning situation. Activities may be sponsored by particular institutions or programs such as science centers, libraries, museums, zoos, planetariums, aquariums, community centers, schools, or commercial firms. Alternatively, they may be completely unsponsored and spontaneous, occurring in a home, garage, or online environment.

In these out-of-school science learning environments, K12 teachers and students have a range of information technology appliances and applications with which to engage in informal learning. These include mobile devices, networked laptop computers, digital-game boxes, 3D printers, electronic kits, technology-enhanced exhibits, and other learning technologies. Science learning may also involve the orchestration of different technology components, digital contents, and platforms that together offer an infrastructure to support learners as they pursue a driving question, make a project, engineer an artifact, collaborate with peers, or play a game.

Museum-Based Learning: Technologies and Visualization

Some examples of informal learning technologies installed in science centers and museums include 2D and 3D visualizations projected in theaters, digital domes, or full spheres viewed by visitors including family groups. The National Oceanic and Atmospheric Administration’s “Science on a Sphere” is a 6-ft-diameter spherical screen (see Fig. 1) that displays colorful data about weather and other natural phenomena, projected onto the surface of the sphere from four external cameras. A museum educator can select different datasets to share, turning the projected sphere into a dynamic, colorful display, facilitating discussions with



Technology for Informal and Out-of-School Learning of Science, Fig. 1 Science on a Sphere at Berkeley Lawrence Hall of Science, UC (Photo credit: Tim Ereneta)

visiting school groups about science topics ranging from seasonal weather, geology, climate change, to astronomy. Similarly, interactive touch screen tables or walls are used to display visualizations of watersheds, paleontology, or marine algal blooms in river estuaries. Learners in such settings can even use their own bodies as controllers of projected video or animations, experimenting and manipulating the projected image to examine phenomena in an "embodied" way. Sensors embedded in exhibits can track how the learner's body moves and subsequently changes the projected images provided dynamic feedback. These kinds of experiences are designed to support learning while enhancing the learner's motivation and engagement.

Sponsored After-School Programs and Community-Oriented Workshops

After-school settings are also places where informal learning technologies are being used to support science, technology, and engineering education among school-aged children. One emerging model is seen in the community science workshops and science festivals, where individuals organize themselves into thriving local communities to fashion and craft creative digital media. Learning occurs through the creation and exchange of such media with peers and can happen in local community centers, schools, homes, shops, and storefronts. Social media, digital libraries, online discussion forums, and e-commerce sites are used to support such communities and bring people together online and face to face. For example, in a school, community center, museum, garage, or county fairground, a facilitator might show learners how to use various fabrication and design tools to create prototypes of artifacts. These tools may include computer-controlled milling machines, laser cutters, desktop 3-D printers, or programmable electronics and sensors. In the same way that desktop printers enabled self-publishing in the 1980s, personal design and manufacturing have been enabled by open-source programming tools (e.g., Arduino, 123D, Scratch) and low-cost personal fabrication technologies that empower learners to create tangible artifacts to take home for further reflection and play. Sometimes referred to as the DIY ("Do It Yourself") or the Maker Movement, education stakeholders are advocating such hands-on learning opportunities because they create rich opportunities for project-based learning and inclusion of engineering in the K12 curriculum and motivate students to consider engineering and technology-related careers.

Citizen Science: Information Technology to Support Science in the Community

Citizen science is a participatory approach to science education that engages students, amateur scientists, and the public in scientific research, enabled by technologies such as Web-based observation forms, probe ware, and digital imagery. Citizens are engaged in real science investigations on personal health (e.g., safe drinking water), regional livelihood (e.g., locally sustainable farming practices), or global issues (e.g., climate change or invasive species). Citizens can contribute observations of the natural world, such as counting the recent blooms, bees, or birds in their backyard. For example, the Great Backyard Bird Count project provides online tools to enable citizens to enter data collected from a 15-min observation in their backyards, helping scientists to track migratory birds or track invasive species. The FieldScope project from the National Geographic Society invites teachers and students to map a watershed with online tools that help them draw flow paths, enter water quality data, and upload photographs of a selected site. Additional visual layers can be selected to display data in the context of human geography, including sediments and land cover. Scientists then make use of contributions that are made by students or citizens to corroborate or augment their own datasets. Tools for these interventions may include cameras on users' personal mobile phones or specially developed Web applications for uploading and sending data to a shared database. Students can also engage in the data analyses through scaffolds provided by well-designed online tools. For example, the Zooniverse project invites the public to help identify objects they see in images of the seafloor, collaborating with oceanographers to indicate whether they see fish, scallops, and other organisms in a particular digital image and provide basic measurements through the "click and drag" of a mouse to describe whether the seafloor is sand or gravel. Such contributions from citizen scientists help the scientific project's team to classify from a collection of 40 million images, by HabCam, a habitat mapping underwater vehicle codeveloped by scientists, fisherman, and engineers. Information technology for citizen science has allowed the wisdom of crowds to help calibrate, validate, and gain consensus on data collected, engaging students and citizens in the practices of science.

Research on informal science learning can leverage novel approaches that embed technology as tools for research, evaluation, and assessment. Moreover, informal learning environments are creating opportunities to study learners' gains in content understanding and skill development as well as their engagement, beliefs (i.e., about the nature of science), practices, and motivation. While empirical studies of school learning have far outnumbered those of informal learning, there is a substantive body of research that investigates the impact of informal learning, including any contributions to science learning and interactions with school-based learning.

Cross-References

- ▶ Citizen Science
- ▶ Field-Based Data Collection
- ▶ Handheld Devices
- ▶ Learning Science in Informal Contexts
- ▶ Museums
- ▶ Technology for Science Education: Research

Technology for Science Education: History

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Introduction

As new technologies emerge, they are soon applied to educational aims. In science education, these efforts coincide with the rapid and continued advances in technology and the growing recognition that science education should go beyond teaching facts by taking a more project-based approach where students can engage in more substantive science projects. Thus, many technology projects for science education have included science inquiry activities, emphasizing science processes and methods in addition to science content (more information on many of the systems and research described here can be found in larger comprehensive reviews, such as National Science Foundation (2000) and Quintana et al. (2004)).

Early Technology Systems

Two early ideas about how technology could support science education were microworlds and probeware. The microworlds concept emerged from the work of Seymour Papert, who defined microworlds as "a subset of reality or a constructed reality whose structure matches that of a given cognitive mechanism so as to provide an environment where the latter can operate effectively. These concepts lead to the project of inventing microworlds so structured as to allow a human learner to exercise particular powerful ideas or intellectual skills" (Papert 1981). Computers provided a platform for microworlds that represented some real-world entity, i.e., the "constructed reality" plus a set of tools for people to build, interact with, and analyze that world. Some microworld systems allowed students to model complex systems and natural phenomena, providing a conceptual space filled with objects and agents that interact in ways defined by the student to facilitate active investigations and adjustments to the model over time. Logo, developed by Papert and his colleagues in the 1960s, was an early programming language that children could use to develop and explore microworlds.

Probeware involved the use of data acquisition devices for real-time data collection and software to analyze that data. Pairing data collection probes with computers led to the development of microcomputer-based labs (MBLs), where probes could be connected to computers so students could organize, visualize, and analyze the data being collected by the probes. This led to the development of probe kits, computer interfaces, and software that allowed probes to be used in science classrooms. Research groups such as The Concord Consortium, Computer as Learning Partners, and LetUS were early proponents of the probeware and MBLs, pairing these with classroom activities to guide teachers in using such tools within a science curriculum.

Microworlds and probeware were not necessarily new to professional scientists and researchers, who had already employed computers and data gathering probes for some time. With the advent of personal computers, student-appropriate versions of these tools emerged for science classrooms. Many systems followed in this tradition, such as NetLogo, Star Logo, Boxer, and Scratch. These systems were useful in their own right as modeling environments, with particularly strong applications in science. Microworlds and probeware were also significant because they laid the groundwork for new technology projects that expanded the level of science activity but retained an emphasis on inquiry, investigation, data collection, and modeling.

Personal Computers in the Classroom

The spread of personal computers in schools and homes and the increase in project-based science education in the 1980s and 1990s saw the development of technology tools to support students with various aspects of scientific inquiry. Microworlds and probeware provided some basic functionalities for performing and exploring scientific activities and phenomena, but this new generation of tools began to explore broader, supportive inquiry environments with various functionalities and scaffolding features to support students in the inquiry process.

Other software supported specific types of visualization to help students interpret scientific data using through accessible tools and representations. Examples of these types of tools include MyWorld, a geographical information system that supported middle school students with spatial visualization by overlaying geographically based data and maps. Another example was eChem, a molecular visualization tool for students to view molecules in different ways (e.g., ball-and-stick view, space-filling view, etc.) and interact with the molecules by spinning and moving them to see characteristics of the molecules.

Building on the microworld concept, projects moved beyond the use of visualization to help students build and think about scientific systems and phenomena. The Molecular Workbench project expanded on the visualization approach with an authoring system to support the creation of webpages that integrate text and functional components for chemistry visualization, simulation, and modeling. These components could be selected from an open-source library to help educators create a range of chemistry experiments, simulations, and curricula. Model-It was a general system dynamics tool for students to plan, build, and test models of systems. Students created system models by defining objects in a world, variable for those objects, and relationships between different variables. Students could then run the model to observe the changes in variable values due to the defined relationships and then iteratively refine the model. GenScope supported learning about genetics, with students creating different species of “dragons,” then comparing their genetic profiles with other dragon mutations and the larger dragon population. Students could modify the genetic profiles of their dragons and see the impact of those changes at the gene, cell, species, or population level.

Learning Environments

Further expanding the scope of student inquiry, other projects developed learning environments that supported the overall science inquiry process. Some of these tools could be thought of as process-oriented “shells” composed of a front end illustrating the different activities and subprocesses in the science inquiry process. Other tools for those different activities were then integrated behind this front end. Examples include the STAR Legacy system, Symphony, and ThinkerTools. STAR Legacy guided student investigations by representing inquiry projects as a cycle of steps, such as idea generation, research, and explanation. Symphony explored the notion of “process scaffolding” by integrating a set of planning, data collection and visualization, and modeling tools behind a front end that used process diagrams and reflective prompts to illustrate the main science inquiry process and activities. The ThinkerTools project used different visual representations of the larger inquiry process, providing students with associated tools needed for the different scientific activities in that process.

Other learning environments supported students with specific content domains or approaches to science inquiry, such as experimentation, design, or problem solving. The Learning through Collaborative Visualization (CoVis) project integrated different types of data collection, visualization, and analysis tools, plus a collaborative notebook, database, and mentor interaction to support collaborative student groups exploring weather and climate issues. The Biology Guided Inquiry Learning Environment (BGuILE) provided a set of tools for collecting, viewing, and comparing data, making field observations, and developing a scientific explanation. These tools were situated within a specific problem scenario that provided a framework for an investigation (e.g., investigating issues about finches on the Galapagos Islands to teach about ecosystems, natural selection, and changes in animal populations). Another example was the Knowledge Integration Environment (KIE) project and its successor, the Web-Based Inquiry Science Environment (WISE) project, which integrated different tools and materials with "inquiry maps," expert hints, reflection prompts, multimedia information and simulations, explanation and argumentation development, and templates to support different types of inquiry activities.

New Advances in Technology

As technology moves beyond the desktop computer, efforts continue to apply emerging platforms, paradigms, and devices for purposes of science education. Current efforts focus on mobile devices (e.g., smartphones and tablets), social media (Twitter, blogging, and wikis), and "mixed reality" environments where physical spaces or objects are embedded with technology. Some new projects follow the tradition of the inquiry environments and tools described earlier, but others are leveraging the unique characteristics of these new technologies to support new forms of science learning and instruction.

Mobile devices provide students with new tools to use in a range of science learning activities across formal (e.g., classroom, homework) and informal (e.g., parks, museums) contexts. Early tools included Chemation, a project for Palm devices that allowed students to create flipbook-style animations of molecules that reflected their understanding of chemical reactions. Other mobile tools allow students to collect scientific data in various locations. Some of these devices allow more traditional probeware to communicate with smartphones, tablets, or other proprietary mobile devices (e.g., the SPARK System) so students can collect numerical data for further study. Other projects, such as the BioKIDS or Project Noah, support students in collecting data and field observation to be used in subsequent inquiry activities. Recently, projects have made progress in the design and research of mobile inquiry environments. The Zydeco project, for example, supports not only the collection of different data (e.g., photos, video, audio, text) but also a broader set of science inquiry activities (e.g., planning, data collection and analysis, explanation) on smartphones, tablets, and the web.

Other projects are exploring more novel ways that mobile devices can be used in science education. One approach involves participatory simulations, where students use the mobile device to become agents within a simulation in a physical space, such as the classroom. Such simulations have been used to study epidemiology, population dynamics, and other complex systems. Thus, rather than create models and simulations on the computer, students essentially become the simulation, using mobile devices to display information about the agent they represent and the relationships with other agents (i.e., other students) in the physical space with whom they can interact, thus experiencing the system more directly.

Participatory simulations serve to bridge technological and physical environments, leading to new ideas about how the combination of physical spaces and technologies can support scientific activity. One approach is called embedded phenomena (EP), where computer displays or other data instruments are embedded into a physical space to represent some scientific phenomenon. The WallCology EP embeds computer displays in the walls of classroom to reveal an imaginary space behind the walls, where several species of digital insects inhabit various habitats and conditions. Much like students who explored microworlds, students in WallCology observe these new virtual features of their physical environment, taking data measurements, making observations, and testing predictions, then discussing their ideas. The EvoRoom project embeds and coordinates large displays (projectors and smartboards), mobile devices, and dynamic representations into the classroom space, creating an immersive rainforest simulation where students make observations and work with the dynamic visualizations of their collective inputs to discuss progress of the inquiry community.

Conclusion

Some consistent themes can be seen across the history of technologies for science education. Early ideas about probeware inspired tools to help students collect, visualize, and analyze scientific data. The microworld perspective has inspired environments that support students in the process designing and observing models and simulations. A lineage of progressively sophisticated tools has paralleled the emergence of increasingly responsive and well-instrumented environments that supported students as they investigate science ideas and methods. New technologies allow students to work with many forms of data, to collaborate dynamically with peers, or to become part of a "physical microworld" where Papert's notion of constructed reality is now enacted within a physical setting, augmented by virtual elements. New technologies will certainly continue on this trajectory, enabling students to actively engage in the scientific process with student-appropriate materials and representations while that promote deep interactions with peers and inquiry oriented forms of learning.

Cross-References

▶ Handheld Devices
▶ Interactive White Boards
▶ Modeling Environments
▶ Online Inquiry Environments

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Technology for Science Education: Research

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Keywords

Educational technology; Educational technology research

Main Text

There is a productive trajectory of research concerned with the role of technology in science education. Educational researchers have often situated their studies with science domains, given the structured and robust conceptual matter, the defined forms of problem solving and inquiry, or the available research funding (i.e., from governmental science agencies). Studies have investigated the nature of students' misconceptions and conceptual change, as well as problem solving, argumentation, collaboration, data analysis, design, scientific reasoning, and many other aspects of learning and instruction. Such studies typically employ computer and information technologies in order to support and investigate new forms of learning and instruction. New technologies included scientific visualizations (e.g., animations, simulations, etc.), probeware, models, data analysis, online discussions, and scaffolding environments (i.e., to support inquiry, knowledge building, and knowledge communities). Researchers have explored learning in science classrooms, playgrounds, households, museums, and other informal learning environments. Due to the wide scope of settings, topics, and approaches, it is not possible to address all aspects of the research, such as early work concerning educational radio and television (Tyack & Cuban 1995). Hence, the reader is encouraged to pursue the references cited, as well as the many substantive reviews that are available (e.g., Sawyer 2010). Additionally, the article in this Encyclopedia on the History of Educational Technology (Quintana 2014) presents an excellent summary – a history that has been driven largely by educational research.

Researching Science Misconceptions

Technology has played a prominent role in the research domain concerned with students' understanding of science topics, including the study of novice-expert differences (i.e., in knowledge, problem solving, and reasoning), and conceptual development. Many studies have explored the nature of student "misconceptions," with the aim of informing instruction that could help students to redress problematic ideas or build upon their existing understandings in a constructivist fashion. Researchers have designed computer-based materials that capture student ideas (i.e., by detecting patterns in their responses) and enable productive learning. In the ThinkerTools environment, for example, White and Frederickson (1991) investigated students' conceptions of force and motion using computer animations. Students could manipulate a simulated physical system in ways that would be difficult or impossible with a real-world system, all the while revealing evidence of the nature of their understandings. Using the Heat Bars simulation, Songer and Linn (1988) explored students' ideas about heat and temperature by allowing them to manipulate the material composition of a simulated bar (e.g., metal, wood or glass) and observe heat "flowing" through the bar. Many other studies explored computer-based tutoring environments, using artificial intelligence to create "models" of student reasoning, which were used to inform exchanges between the student and an automated tutoring environment (Anderson et al. 1995). Throughout the 1980s and 1990s, the computer emerged as a resource for researchers to capture, diagnose, and respond to student ideas, opening the door to a wealth of research about the nature of learning and instruction.

Scientific Models and Visualizations

Technology has also figured prominently in research concerned with the role of models and other scientific visualizations. Scientists and science learners engage with myriad forms of visualizations relating to conceptual or mathematical relationships, problems and solutions, or data tables and graphs. Scientists frequently make use of dynamic, computer-based simulations that support conceptualization or analysis, and visualizations are seen as an invaluable component in science learning. For example, sketches of molecular level concepts, like DNA, or processes, like mitosis, help to make the microscopic more visible and accessible to learners. The role of digital media has expanded greatly within every scientific discipline and, correspondingly, in science education. Computer-based visualizations offer clear advantages, such as the animation of concepts, ability to zoom in, rotate, play simulations backward and forward, or render events that can take generations to unfold into an observable timeframe. Science teachers often make use of visualizations using computer projectors or engage students with a myriad of Web sites using tablets, laptops, or computer labs.

Educational researchers have investigated the application of such media in learning and instruction: Should students make use of the same tools and representations employed by scientists? Should they engage with intermediate models, to help them gradually build more sophisticated ideas? How can multiple forms of visualization be interconnected, to support students? What kind of guidance is needed, and what forms of inquiry can best support students' and teachers' effective use of scientific media? How can visualizations support social or collaborative learning? A biological simulation environment called GenScope (Hickey et al. 2003) allowed students to manipulate the genes of a fictional species of dragon, then run the simulation through thousands of generational cycles, in order to study the variation of traits in individual dragons (e.g., "has wings," "breathes fire"). In another research environment called Model-It, students were supported in exploring the causal relationships within a system (e.g., a watershed ecology) using a dynamic modeling environment (Stratford et al. 1998). Other systems have investigated whether the linked usage of multiple representations for science topics can productively challenge students in the construction of scientific understandings. Several large research centers, such as technology-enhanced learning in science (TELS), have investigated effective designs of curriculum and assessments that integrate such materials and how students and teachers can best interact with them (Linn et al. 2006).

Technology-Enhanced Inquiry Environments

A third area of research is concerned with technology-enhanced learning environments that provide students with support as they engage in online inquiry projects, hands-on design activities, field-based research projects, or multiuser collaborations. Researchers design computer-based learning environments to embody their goals or conjectures about learning, embedding their hypotheses within materials, activities, and tools. For example, researchers who want to understand how students find and critique relevant resources have developed environments that include supports for the evaluation of evidence and formation of arguments (Bell 2004). To study how student reflections might foster understanding, learning environment were developed that included prompts and supports for student reflection. Such environments can support collaboration, design projects, experimentation, modeling, or various other forms of inquiry learning. For example, BGuILE, the Biology Guided Inquiry Learning Environment (Reiser et al. 2001), supported students in developing and testing their own scientific hypotheses about evolutionary biology, based on carefully constructed data sets. The technology environment supported students as they inspected data, read case studies, performed analyses, and created arguments. The Web-based Inquiry Science Environment (WISE) offers a scaffolding framework for short inquiry projects where students reflect on "evidence" (in the form of carefully designed or found Web sites), create their own artifacts (drawings, concept maps, etc.) and participate in online exchanges with peers. WISE can support a wide range of pedagogical designs, with more than 20 configurable inquiry tools and an authoring system that allows researchers or teachers to create any desired sequence of activities and materials (Slotta and Linn 2009). The notion of a learning environment that scaffolds students and teachers as they engage in new forms of learning and instruction is one that will continue to drive many lines of research and innovations for science classrooms.

Immersive and Multiuser Online Environments

Taking advantage of new technology features and functions, researchers have begun to explore how virtual worlds or multiuser virtual environments ("MUVEs") can support students or teachers in science learning. Not only could this approach potentially bridge individuals or groups that were physically separated, it might also allow for new kinds of interactions, experiences, or exchanges. For example, in the River City project (Nelson et al. 2007), a classroom of students gathers online (each student working at his or her own computer) to explore a nineteenth century American town that is afflicted with a mysterious health condition. Each student adopts a digital avatar and joins up with peers to investigate various sources of evidence throughout the town, collecting data, examining patterns, and speaking with local guides and consultants. The research on these environments suggests a great potential for shared online experiences, as reflected by the amount of activity devoted to such interactions by the gaming community. Educational researchers will continue to investigate immersive multiuser environments for science and other domains, with likely applications in K-12, home, and online learning contexts.

Distributed Learning Environments

Technology-enhanced environments have now escaped the confines of the computer screen. Recent advances in networked technologies and new technology platforms (e.g., tablets or multi-touch tables) have enabled the development of instrumented learning environments that employ wireless sensors, probeware, handheld computers, and other devices to support student activities across a wide range of learning contexts. For example, students might perform Web-based activities at home or in the classroom, then go out to the playground or local woodland and use a mobile phone or tablet to collect observations, which are then compiled into a larger data set to be used in subsequent inquiry activities (Songer 2006; Milrad et al. 2008).

Networked approaches have also been advanced, such as Mister Vetro (Loannidou et al. 2010) where students work in small groups to cooperatively control an animated model of human physiology that is projected on a large display before the group. Mr. Vetro has interconnected respiratory, circulatory, and nervous systems, and each student controls a different aspect of the simulation using their own personal handheld device (i.e., phone or tablet). The group explores the impact of different interventions (e.g., exercise, eating) on Mr. Vetro's physiology and must work together to keep him healthy. In another form of networked learning, Colella (2000) provided each student in the class with a small necklace containing an infrared transmitter and receiver called a "Thinking Tag," and organized them into a collective (i.e., the whole class) activity about disease transmission. Every student was a potential virus carrier, with the aim of greeting as many people as they could without contracting the digital virus. Initially, just one student started out with the virus, but after moving around the room for just a few minutes and interacting with peers (via infrared "beaming"), nearly every child in the class had become infected. By carefully designing instruction that incorporates these physical, embodied experiences, the teacher or research can help students gain a deep understanding of the pertinent science concepts (i.e., human body systems or disease transmission).

Social or Community-Based Inquiry

Other lines of research have employed technology to support whole class or even multiple classrooms of students inquiring together as a "knowledge community" (Bielaczyc and Collins 2006). Recent advances of Internet technologies have emphasized social forms of interaction, sometimes referred to as "Web 2.0," which include collaborative writing environments like wikis, social networking environments like Facebook, and content communities like YouTube. These developments have inspired educational researchers to create technology environments that support collaborative and cooperative knowledge construction. Scardamalia and Bereiter (2006) have explored the notion of knowledge building, where students in a classroom work as a knowledge community, using a technology platform called The Knowledge Forum with the aim of advancing ideas (akin to a community of scientists who work within a discipline). Peters and Slotta (2010) employed a wiki to engage five sections of a high school biology course (totaling 132 students) to cooperatively construct a comprehensive knowledge base concerning Canadian biodiversity. Once completed, this wiki (roughly 300 Web pages) provided all students with a well-structured resource for subsequent inquiry activities. As Web 2.0 and networked technologies become more accessible and familiar to researchers, we should expect more studies where students work collectively to contribute and evaluate content, interact with peers, and develop shared resources. Researchers will be challenged to conceptualize new forms of productive interactions for learning and instruction, and teachers will be challenged to develop new pedagogical understandings and practices required to coordinate such socially oriented approaches. Teacher practices and professional development will be an important aspect of such research.

Learning in Museums or Science Centers

Another area of research where technology has played an important role is that concerned with science learning in museums and other informal learning environments, such as aquariums, nature centers, or guided field trips to the local stream or forest. Researchers have designed engaging exhibits, activities, and materials that allow students to experience science phenomena in ways that are inaccessible to classroom instruction. Science centers and museums are investing in sophisticated projection systems for use in theaters, digital domes, or other interactive surfaces. For example, the Science on a Sphere, developed by the US National Oceanic and Atmospheric Administration, is a 6-ft diameter spherical screen that displays colorful images of a planet, moon, or star (e.g., weather patterns or solar storms), projected from four external cameras. Similarly, interactive multi-touch tables or walls are used to display visualizations of raindrops, rivers, watersheds, or microbes. One or more learners could then experiment and manipulate the contents of the displays to examine, for example, how microbes affect ocean temperatures or rain flows within a watershed. Using projectors and computer-vision techniques, students are asked to "kick" digital asteroids, projected onto the floor, to help them understand inertia and the physics of movement and collisions (Lindgren and Schwartz 2009). Such forms of media interaction are a frontier for learning research, often designed to support tangible and embodied interactions, where the learner's physical engagement with materials is seen as an essential aspect of the design (i.e., as opposed to simply reading or watching on a screen).

Future Research with Technologies

Technology has transformed nearly every major social institution, including business, government, the arts, and – increasingly – education. While one could argue that classrooms today remain largely the same in form and function as those of 50 years ago, there is evidence that technology is making an impact. Higher education is rapidly evolving through the impact of online learning, with "flipped classrooms," audience response systems (also known as "clickers"), and other innovations. In K-12 science classrooms, interactive whiteboards and computer projectors are increasingly common, and teachers are gaining prowess in how to use them. Students are empowered as never before, with the world of information and social networks at their fingertips (e.g., YouTube, Google, and many other sources of content).

Teachers can access resources, yet they are rightfully cautious in changing their practices without compelling evidence of success. To simply give a science teacher a classroom set of laptop computers, for example, would not be sufficient impetus or resource for her to begin using that new technology in a substantive way. Many questions remain. How should teachers engage students with such technologies in a meaningful way? What is the role of the teacher, when students are engaged online? What materials and what activities are the most effective? These questions remain largely unanswered, as educational research is still in the early stages of understanding how technology can transform science learning and instruction. Research is making some progress toward this end, as the above sections reveal. Investigating how technology can help students to develop deep understandings, interact productively with peers, and access scientific ideas is at the forefront of the research agenda. Educators will be able to access the body of empirical findings and the wealth of new materials and learning environments as they emerge.

Cross-References

- ▶ Digital Resources for Science Education
- ▶ Games for Learning
- ▶ Handheld Devices
- ▶ Immersive Environments
- ▶ Inquiry, Learning Through
- ▶ Online Inquiry Environments
- ▶ Tangible and Embodied Interactions for Learning
- ▶ Technology for Informal and Out-of-School Learning of Science
- ▶ Technology for Science Education: History

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Technology, Assessing Understanding of

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The definitions of technology for this encyclopedia entry are based on documents produced by national sets of experts. The definitions of technology are the starting points for developing assessments of understanding of its forms and uses. This encyclopedia entry begins with a summary of prominent conceptualizations of technology. Descriptions of some potential types of assessment tasks and items to test understanding of technology are provided.

Definitions of Technology

Technology is defined as any modification of the natural or designed world developed to fulfill human needs or desires. Technologies are products and processes resulting from application of engineering design processes and may often be based on scientific knowledge. Technologies also often function as tools and processes used to support engineering design which is defined as a systematic and iterative approach to designing objects, processes, and systems to meet human needs and wants. The effects of technology on society and the world are often cited as key concepts in understanding the needs driving development of technologies and the consequences of technology development.

Sources of Conceptualizations of Technology

Framework for K-12 Science Education and **the** ***Next Generation Science Standards*** (NRC 2011; NRC 2013). The framework includes engineering and technology as they relate to applications of science. Engineering is used to mean engagement in a systematic design practice to achieve solutions to particular human problems. Two core engineering ideas are specified. The first is engineering design – how engineers solve problems. Technologies may be used to support solving problems, and technologies may be the outcomes of the engineering design process. The second core idea is understanding of the links among engineering, technology, science, and society. The framework describes grade-band end points for each of the three components.

The *Next Generation Science Standards* (NGSS) provide more specific guidance for assessing understanding of technologies, their use, and their influences on society and the natural world, for example, knowing that simulations are useful for predicting what would happen if various parameters of the model were changed. Also, technology use varies from region to region and over time and is driven by findings from scientific research and by differences in such factors as climate, natural resources, and economic conditions. The NGSS present performance expectations that have been developed to integrate the engineering core ideas with crosscutting concepts such as systems and models and cause and effect and also with science and engineering practices.

Technology and Engineering Literacy (***TEL***) ***Framework for the 2014 National Assessment of Educational Progress*** (NAGB 2010). The framework defines technology and engineering literacy as the capacity to use, understand, and evaluate technology as well as to understand technological principals and strategies needed to develop solutions and achieve goals (NAGB 2010). The framework lays out three areas of technology and engineering literacy, the types of thinking and reasoning practices that students should be able to demonstrate, and the contexts in which technologies occur. Three main assessment areas are specified: design and systems, information and communication technology, and technology and society. Within design and systems, three subareas of essential knowledge and skills are identified: nature of technology, engineering design, system thinking, and maintenance and troubleshooting.

Principles for the nature of technology expand the scope of common conceptualizations of technology beyond computers and the Internet. The broader view includes every way people manipulate the natural environment to satisfy needs and wants. Therefore, technology includes all the various devices and systems that people make to fulfill some function. The framework lays out key principles for the nature of technology: (1) technology is constrained by the laws of nature; (2) scientists examine what exists in nature and engineers modify natural materials to meet human needs and wants; (3) technological development involves creative thinking; (4) technologies developed for one purpose may be adapted for other purposes; (5) science, technology, engineering, mathematics, and other disciplines are naturally supportive; (6) the pace of technological change has been increasing; and (7) tools help people to do things efficiently, accurately, and safely. The framework then lays out assessment targets for the nature of technology for grades 4, 8, and 12.

The TEL framework describes engineering design as an iterative, systematic process for solving problems. The process begins with stating a need or want and the criteria and constraints of the challenge. Then potential solutions are explored referencing relevant scientific and using technologies. Potential solutions are compared, and models and prototypes are constructed, tested, and evaluated to see how they meet the criteria and constraints of the problem. The framework specifies key principles of engineering design and proposes assessment targets for grades 4, 8, and 12.

The framework also specifies components, principles, and assessment targets for grades 4, 8, and 12 for the prominent technology area of information and communication technology (ICT).

ICT is presented as a separate assessment area within technology and engineering literacy because of the central place ICT plays in learning and functioning in school, the workplace, and daily living. ICT subareas to assess include understanding and use of technologies for (1) construction and exchange of ideas and solutions, (2) information research, (3) investigation of problems, (4) acknowledgement of ideas and information, and (5) selection and use of digital tools. Assessment targets for ICT at grades 4, 8, and 12 are presented.

The area of technology and society addresses the effects that technology has on society and on the natural world and the sort of ethical questions that arise from those effects. The area is further divided into interaction of technology and humans, effects on the natural world, effects on the world of information and knowledge, and ethics, equity, and responsibility. Assessment targets for grades 4, 8, and 12 are presented.

Each of the frameworks and standards described above can serve as resources for specifying the technology understanding to be assessed. In the following section, the use of a systematic assessment design framework is presented to support the selection or development of assessments.

Assessment Methods

Reference to the varying definitions and contexts of technology can provide the bases for core technology concepts to be tested. The assessments of understanding technology concepts may vary the cognitive demands or levels of reasoning required. Cognitive demands could involve simply identifying definitions and lists of features of technologies and their uses. Knowledge about technology tools is less challenging than knowledge about the functions they serve and how they may be best used. More demanding would be to require analysis of the selection, development, and uses of technologies as supports or products of engineering designs in the multiple contexts such as academic domains, agriculture, manufacturing, or medicine. The realm of ICT assessment invites assessments of understanding how digital and media tools can support a range of strategies such as planning, accessing and organizing information, representing and transforming information and data, analyzing and interpreting, designing products, critically evaluating, collaborating, and communicating (Quellmalz 2009). Assessments of understanding could also ask for evaluations of selections, development, or uses of technologies by others for specified purposes in multiple contexts.

Assessments of understanding technology in science and engineering could involve students' understanding of the use of science and engineering "tools of the trade," such as computer design software, simulations, modeling software, search engines, social networking, visualizations, and graphs (Quellmalz et al. 2009). Understanding of technology in science and engineering could also involve reasoning about the technological artifacts and processes suited to addressing stated needs. Scoring and reporting of responses to these types of tasks and items would then provide data that could be used diagnostically to inform further instruction or to support a summary proficiency reports.

Cross-References

- ▶ Computer-Based Assessment
- ▶ Engineering, Assessing Understanding of
- ▶ Engineering Design, Assessing Practices of
- ▶ Public Communication of Science and Technology
- ▶ Science, Technology, and Engineering Interrelationships: Assessment of the Understanding of
- ▶ Technology Education and Science Education

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Television

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Social scientists have long been examining mediated depictions of science and technology with hopes of better understanding their influence on learning, opinion formation, and behaviors relative to scientific issues. The majority of this research has traditionally focused on journalism, but in the 1980s, researchers began seriously considering the role of television as a potential platform for informal learning about science given the medium's role as the public's primary science touch-point.

The majority of these early examinations found mostly unfavorable portrayals of science and scientists. This research – mostly qualitative – suggested, for example, that commercial television disseminates primarily dubious images of science, minimizes the inherent uncertainty of the scientific process, and shows scientists as extraordinary and vastly different than ordinary citizens. Quantitative assessments conducted by communication scholar George Gerbner and his colleagues during the 1980s also indicated that scientist characters in primetime television programming suffered a higher ratio of negative characteristics (e.g., evil, disturbed, villainous) and were more likely to be victims of violence, as compared to other occupations.

More recent analyses, however, suggest that television depictions of science and scientists have become less negative. A report conducted in 1999 for the US Department of Commerce suggested that the television landscape no longer demonstrated any type of systematic negative portrayal of scientists. And an empirical analysis of primetime TV programming broadcast between 2000 and 2008 found that while scientist characters are uncommon in these shows, when present they are considerably more likely to be categorized as "good" than as "bad" (Dudo et al. 2011).

A more granular strand of research in this area has examined the depictions of science and scientists in both educational and entertainment television programs targeted toward children and middle schoolers. Some notable findings from the studies examining children's science shows (e.g., *Bill Nye the Science Guy*, *Beakman's World*) include that science is often shown as fun, a solution to problems, truthful, and a part of everyday life. These studies also find, however, that these TV shows paint mixed pictures of scientists, in some cases depicting scientists as elite and predominately male Caucasians, while in other cases depicting science as being intended for everyone and gender neutral (e.g., Long et al. 2010). In sum, although there is no singular theme about science or scientists present in television programming, recent research suggests that there may be an overall trend within television away from the historically negative portrayals unearthed in early examinations of the medium.

The research examining portrayals of science and scientists on television has fueled a line of work examining how these portrayals contribute to public understanding of and attitudes toward science (e.g., Nisbet et al. 2002). These studies have been guided primarily by two theoretical frameworks – cultivation theory from communication studies and social cognitive theory – and have found highly variable audience effects. Some of this work has looked for correlations between the amount of time viewers spend watching television and their general attitudes toward science, with the initial studies finding a negative attitude (e.g., the more time spent watching television, the more negative the attitude toward science) that has not been supported in recent replications. Other recent empirical studies have examined potential connections between different genres of television programming and viewer perceptions of science and specific scientific issues. For example, frequent viewing of religious TV programming has been linked with unfavorable attitudes toward scientific issues, frequent viewing of dramatic and comedic programming has been linked with support for agricultural biotechnology, and frequent viewing of science fiction programming has been linked with support for therapeutic cloning. Some research has also examined the audience effects of specific shows. The immensely popular TV show *CSI: Crime Scene Investigation*, for example, has received much scholarly attention (e.g., Ley et al. 2012) and has been linked to increases in viewers' awareness of and interest in forensic science and their belief in the reliability of DNA evidence.

The research summarized above focuses on the effects of science television on audiences in informal settings. Research, however, has also focused on the effects of science television in classroom settings. This body of work has had two main areas: experimental research exploring how science television content characteristics influence student learning, and case studies by educators and scientists evaluating and describing their use of science television (and fictional films) in their curriculum. Overall, these efforts have identified numerous positive outcomes from the pedagogical use of science television and films in the classroom. Some of the identified benefits include increasing student engagement, providing visual and enjoyable connections between scientific concepts and applications, establishing mental images about science, helping students better identify illustrations and violations of scientific principles, enhancing student interest in science by drawing connections to social issues, and highlighting the interdisciplinary nature and uncertainty of the scientific process. Additionally, this practice has also been observed to help teachers better understand students' preconceptions and attitudes toward scientific subjects.

In sum, this corpus of work demonstrates that television programming contributes to viewers' interest, identification, learning, and perceptions relative to science in both informal and formal settings. This point has been reached in several recently commissioned reports that synthesize the state of research related to informal science learning (e.g., Bell et al. 2009). Television, it seems, is likely to continue to play a major role in the ways that people learn about science, via both educational science programming for children and adults, and entertainment programming with narratives that involve science and scientists.

Cross-References

- ▶ Broadcast Media
- ▶ Online Media
- ▶ Print Media

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Test

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Keywords

Accountability; Common assessment; Diagnostic assessment; Formative assessment; Interim assessment; Measures; Summative assessment; Testing; Validity

A test is a way by which teachers can determine the extent to which students understand a topical area and can demonstrate such understanding. There is a growing abyss in education about testing practices and the purposes for which tests are being used. While there continues to be an emphasis on measuring student performance for the purposes of accountability, there also is a parallel emphasis that focuses more on understanding performance so that appropriate instructional steps can be identified. The distinction is between summative and formative assessments. Summative assessments are those that measure the result of a course, a chapter, or a unit of study. Formative assessments seek to identify students' learning weaknesses and strengths so that teachers can then determine what instructional steps are needed to address those needs (see Black and Wiliam 1998; Heritage 2010). The distinction also is between assessment *of* learning and assessment *for* learning (Stiggins 2005). The former measures what and how much learning has occurred. The latter seeks to identify what students have learned or not learned to inform instruction.

One helpful way to think about tests is to consider a pyramid (see Love et al. 2008). At the top of the pyramid are the summative assessments, those given primarily for accountability uses and administered annually. In many instances, these are high-stakes, standardized tests. At the bottom of the pyramid are classroom activities, teacher-made quizzes, projects, and portfolios, given daily or weekly. These activities can be teacher made or be provided as part of the textbook and curriculum.

Between the two extremes are benchmark and interim assessments that may be given quarterly to determine learning progress. Benchmark assessments are given at various intervals throughout a school year. They measure student performance against specified academic standards and explicit learning goals and are aligned to the sequence of the curricula (Herman et al. 2010). Such tests can be used for various purposes, including to inform instruction at the classroom, school, and district levels. Interim assessments (a) provide data about student knowledge and skills; (b) are administered at regular intervals throughout the school year; and (c) have results that are aggregated and compared across classrooms, schools, and districts (Goertz et al. 2009). Interim assessments can be used both for formative and summative purposes.

At the next level of the pyramid are formative and diagnostic assessments. These tests are administered several times a month to provide teachers and students with information about learning strengths and weaknesses. Formative assessment is not just a characteristic of the test per se. It is a process by which the assessment occurs (Bennett 2011). The purpose of such assessments is to improve the teaching and learning process by providing teachers with diagnostic data that can be used to adjust instruction to accommodate the learning needs of the students. The assessments are used at the classroom and individual student levels.

These tests form a continuum of relevance to instruction. The more removed a test is from instruction and the longer the duration from the instructional event, the less instructional validity there is for the assessment. The tighter the feedback loop between the assessment and the instruction, the more likely the test will be able to inform instructional practice.

Another characteristic of a test is whether it is a common assessment. Common assessments are administered in a systematic way across classrooms, schools, or even across districts to facilitate comparative analyses. State summative tests are considered common assessments, as are benchmarks and interim assessments. Common assessments may be developed within a district for course content areas where there are no standardized measures for the purpose of comparing the performance of different schools and classes. For example, in states where science is not included in their state accountability measures, districts may choose to develop common assessments for middle school science, biology, life sciences, or other courses so that educators can compare performance across classes or schools.

Cross-References

▶ Assessment to Inform Science Education

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Textbooks: Impact on Curriculum

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For as long as science has been a school subject, textbooks have been highly influential representations and interpretations of the curriculum to be taught. In most classrooms the impact of the textbook being used is very strong on both the intended and the implemented curriculums, and where the developers of the curriculum also generate the textbook, this impact is particularly striking.

The impact on implemented curriculum derives from the textbook very commonly being the only representation/interpretation of the intended curriculum that students use and often that the teacher uses. Although textbooks are not the only factor responsible for students' learning, in many parts of the world, they constitute the most important curriculum material. Reliance on textbooks is all the more important when teachers are teaching outside their own area of expertise, which is often the case at the middle school level.

The most striking examples of textbook impact on the intended curriculum are curriculum projects that have sought to develop an integrated package of curriculum, textbook, and other materials to support learner and teacher. This pattern was set by the very first of the science curriculum projects, the work of the Physical Sciences Study Committee (PSSC Physics) in the USA in the latter 1950s. PSSC Physics materials included a curriculum, a textbook, specially designed student laboratory equipment, films, and comprehensive teachers' guides to all these materials. In all of the many and varied contexts in which PSSC Physics was adopted, the textbook was the representation of the curriculum to be learned for all students and many teachers.

A current widely known curriculum project that has given serious attention to textbooks and their impact is Project 2061 being developed by the American Association for the Advancement of Science (AAAS 1990) and named for the next year in which Comet Halley will appear. Project 2061 has a focus on developing scientific literacy among students. It is particularly critical of current science textbooks. Typical textbooks, it argues, emphasize the learning of answers far more than the exploration of questions, memory at the expense of critical thought, unrelated items of information instead of understanding in context, and recitation over argument. Beyond the cognitive, Project 2061 analyses indicate that most textbooks do not encourage students to work together and share ideas.

Project 2061 has shown a particular concern for the production of high-quality curriculum materials. The central premise is that such materials should be judged primarily in terms of their likely contribution to the attainment of important and agreed-upon, specific learning goals (in their specific case, such as benchmarks and national standards). Its curriculum analysis procedure uses seven categories of criteria to determine the extent to which the instructional strategy of the teaching material is likely to facilitate students' learning of science:

- *Category I: Identifying and maintaining a sense of purpose*. Is the material understandable and motivating to students? Does each activity have a purpose and its relationship to other activities? Is there a logical or strategic sequence of activities, rather than a collection of activities?
- *Category II: Taking account of student ideas*. Does the material take into consideration the need for prerequisite knowledge and skills, alert teachers to commonly held student ideas (alternative conceptions), and assist teachers in identifying student ideas before introducing the scientific concepts?
- *Category III: Engaging students with relevant phenomena*. Does the material provide multiple and varied phenomena to support the benchmark idea? Does it provide students with firsthand experiences of phenomena?
- *Category IV: Developing and using scientific ideas*. Does the material introduce technical terms meaningfully in order to promote effective communication?
- *Category V: Promoting student thinking about phenomena, experiences, and knowledge*. Does the material include tasks and/or question sequences to guide student interpretation and reasoning about experiences with phenomena? Are students provided opportunities to check their own progress?
- *Category VI: Assessing progress*. Assuming a content match between the curriculum material and the benchmark, are assessment items included? Does the material assess understanding rather than responses that are trivial or based on memorized terms?
- *Category VII: Enhancing the science learning environment*. Does the material help teachers to create an environment that encourages student curiosity, rewards creativity, encourages a spirit of healthy questioning, and avoids dogmatism?

In a survey of 38 nations conducted as a part of the Third International Mathematics and Science Study (TIMSS), the relationship between science curriculum as a policy statement and classroom practice has been explored. In this context, according to Valverde et al. (2002), it is textbooks that are responsible for translating policy into pedagogy, intended into implemented, and are used consistently by both students and teachers in this way. TIMSS has used a curriculum model that distinguishes between curriculum as system goals (intended), curriculum as instruction (implemented), and curriculum as student achievement (attained). As already noted above, textbooks play a mediating role between the intended and the implemented curriculums. Based on this model, Valverde et al. (2002) have collected data from 630 mathematics and science textbooks from around the world. Some of the criteria used to evaluate the textbooks were proposed classroom activities, amount of content covered, content complexity, sequencing of content, and physical characteristics. Findings of the study showed that textbooks published in different countries exhibit substantial differences in presenting and structuring pedagogical situations that are related to grade level and subject matter. Furthermore, the study revealed a statistically significant relationship between textbook content and teachers' coverage of the topics promoted in textbooks, a further indicator of the substantial impact textbooks have on the implemented (and learned) curriculum.

Nature of Science

One of the features of most school science curricula and textbooks is consideration of "what is science," "what is the nature of science," and something whose equivalent is either rare or unknown in all other areas of the school curriculum. Although philosophers of science hold differing views of the nature of science, science educators have generally tried to present a consensus view with respect to how science works and how scientists do science. However, science education researchers and scholars of the history and philosophy of science have frequently been particularly critical of how textbooks misrepresent, truncate, and at times "distort" the scientific endeavor (views of science as a form of Baconian empiricism and simplistic and recipe-focused accounts of a "scientific method" are two common examples) (see, e.g., Kuhn (1970), pp. 137–138; although it is important to note that at times Kuhn also supported the traditional textbook presentation of science content, see Kuhn (1970), p. 165). As part of its concern with the quality of textbooks, Project 2061 has recommended the inclusion of the following ideas about the nature of science in the science curriculum and textbooks:

(a) The world is understandable.
(b) Scientific ideas are subject to change; change in knowledge is inevitable because new observations may challenge prevailing theories.
(c) Scientific knowledge is durable (e.g., Albert Einstein did not discard the Newtonian laws but rather showed them to be only an approximation).
(d) Science cannot provide complete answers to all questions.
(e) Scientific inquiry is difficult to describe as scientists differ as to how they investigate. In other words, there is no fixed set of steps that scientists always follow and no one path inevitably leads to scientific knowledge.
(f) Science is a blend of logic and imagination, namely, formulating and testing hypotheses to figure out how the world works, which is as creative as, for example, composing music.
(g) Science explains and predicts (e.g., a theory about the origins of human beings can be tested by new discoveries of humanlike fossils).
(h) Scientists always look for evidence in order to support their theories; however, interpretation of data can be biased, which requires the contribution of various scientists working on the same subject.
(i) Scientists disagree and are critical of the work of their colleagues and this facilitates progress in science.
(j) Scientific research is affected by the social and historic milieu in which the scientists work.

Niaz and Maza (2011) analyzed the presentation of nature of science in the introductory chapters of 75 US general chemistry textbooks. Some of the criteria for evaluation were the same as those used by Project 2061 (above). Very few textbooks presented the following ideas satisfactorily: the tentative nature of scientific theories; there is no universal step-by-step scientific method; observations are theory laden; scientific knowledge relies on observations, experimental evidence, rational arguments, creativity, and skepticism; scientific progress is characterized by competition between rival theories; different scientists can interpret the same experimental data differently; and scientific ideas are affected by their social and historical milieu. Interestingly, some of the textbooks analyzed referred to a wide range of specific issues in the development of science, such as the discovery of DNA; quantum theory; understanding heavenly bodies for 4,000 years; phlogiston theory and chemical revolution; Galileo, Copernicus, and the church; and Pauling, Sakharov, and nuclear weapons. These episodes from the history of science show the controversial nature of scientific progress.

Cross-References

- ▶ Curriculum
- ▶ Curriculum Movements in Science Education
- ▶ NOS: Cultural Perspectives

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Theories of Science, Assessing Understanding of

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Understanding theories of science has dual meanings depending on the perspectives one holds about what to understand about the theories. On the one hand, understanding a theory deals with understanding the science contents included in the theory. Thus, assessing understanding of theories is construed as the evaluation of how exactly students comprehend the content of a theory and/or interpret natural phenomena using the theory. On the other hand, understanding a theory deals with understanding conceptual and epistemic status of a theory in terms of the nature of science. Thus, the assessment of understanding theories of science is to examine what kind of idea students have on a theory, usually with no regard to the content or domain included in the theory.

Historically the first significant assessing instrument focused on understandings of scientific theories was ***Test on Understanding Science*** (TOUS, Cooley and Klopfer 1963) which had a branch of item groups to examine understanding about the method and aims of science. Although there have been some critics on TOUS, it has some meaningful elements related to theory development. Those are "communication among scientists, scientific societies, theories and models, controversies in science, generalities about scientific method, and unity and interdependence of the sciences."

Another assessing instrument which highly focused on the theories of science is the ***Conceptions of Scientific Theories Test*** (COST, Cotham and Smith 1981). COST sought to incorporate assessing items sensitive to alternative conceptions about the aspects of nature of science and sensitive to the conception with regard to the tentative and revisionary view of science. The tentativeness refers to inconclusiveness of knowledge claims in science and the revisionary view of science refers to revision of existing scientific knowledge in response to changing theoretical contexts. COST consists of 40 likert-scaled items with four subscales such as ontological implications of theories, testing of theories, generation of theories, and choice among competing theories. COST also contains four theoretical contexts for each subscale with a brief description of a scientific theory and some episodes from its history. Those contexts are Bohr's theory of the atom, Darwin's theory of evolution, Oparin's theory of abiogenesis, and the theory of plate tectonics. In addition to these four contexts, COST includes nontheoretical context which is related to general characteristics of scientific theories. The items following the short descriptions in each theoretical context for the subscales were designed to discriminate between two alternative conceptions organized around philosophic aspects of the theories of science. The categories of alternative conceptions for each subscale are realistic/instrumentalist for ontological implications of theories, inductive/inventive for generation of theories, tentative/conclusive for testing of theories, and objective/subjective for choices among competing theories.

Currently the most widely used assessing instrument about understanding of theories of science is the ***Views of Nature of Science*** (VNOS) Questionnaire (Lederman, Wade, & Bell, 1998; Lederman et al. 2002). As the name of VNOS means, the series of VNOSs (VNOS-A to VNOS-E) are assessment instruments to examine ideas on nature of science, which consist of 7–10 explicit and declarative tenets as the type of open-ended survey items with follow-up interviews. Among the survey items, VNOS contains tenets and questions which ask about the tentativeness in scientific theories and the difference between a theory and a law. While VNOS sought to elicit well-reasoned consensus lists between the responses to assessment items and the statements drawn from standard documents about nature of science, it probed learners' general beliefs or views about science and the theories of science not related to specific and actual contexts of science.

Current research on history and philosophy of science suggests that understanding the nature of science should be functional for the dimensions of reliability of scientific claims (Duschl and Grandy 2013). Thus, merely investigating the consensus of declarative tenets is not fully adequate for applying the consensus to personal or social decision making about the reliability of scientific claims or theories. Allchin (2011) proposed a frame of dimensions about how the reliability of science is achieved as knowledge develops, which he called ***Whole Science***. The Whole Science dimensions consist of 10 subcategories which are observations and reasoning, methods of investigation, history and creativity, the human context, culture, social interactions among scientists, cognitive processes, economics/funding, instrumentation and experimental practices, and communication and transmission of knowledge. From this point of view, the assessment of understanding theories of science also seeks for well-informed analysis about the factors that ensure the reliability of scientific claims and theories. Allchin (2011) also provided a prospective prototype of assessment for understanding of theories as well as nature of science, which he called ***KNOWS*** (Knowledge of the Nature of Whole Science).

From the view of naturalized philosophy of science, which focuses more on cognitive and social practices of actual scientists, the development of scientific theories is constructed not by a scientist's individual efforts but by the cognitive, epistemic, and social practices of communities of scientists (Duschl and Grandy 2013). Thus, the contexts of theory improvement and refinement show how scientists respond to new data, interpret them and build a model, and explain a phenomenon with a new theory. The deeper and broader a theory is over time by accounting for new more data, the higher are the advances of explanatory coherence of the theory. Therefore, assessing understanding of theories of science needs to scrutinize the level of sophistication in students' functional understanding of scientific practices from obtaining data through model building toward developing or refining a theory, so that it seeks for advancing the reliability of scientific claims that are drawn from the theory.

Cross-References

- ▶ Facts, Concepts, Principles, and Theories in Science, Assessment of: An Overview
- ▶ Knowledge About and Understanding of Science, Assessment of
- ▶ Nature of Science, Assessing of

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Third International Mathematics and Science Study (TIMSS)

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Keywords

Comparative international studies; International assessment; Mathematics achievement; Science achievement; TIMSS

Overview

The Trends in International Mathematics and Science Study, TIMSS, is an international assessment of student achievement dedicated to improving teaching and learning in science and mathematics in the diverse array of countries that participate in TIMSS. TIMSS has reported on trends in student achievement in science and mathematics at the fourth and eighth grade every 4 years since 1995. TIMSS 2015 will be the sixth assessment, resulting in a 20-year trend line. Because TIMSS monitors achievement at regular intervals, it is a valuable tool for studying whether new or revised educational policies impact achievement. Sixty-three countries participated in the most recent TIMSS assessment in 2011.

At each grade, TIMSS reports on overall science achievement as well as reports achievement in major content domains (life science, physical science, and earth science at grade 4; biology, chemistry, physics, and earth science at grade 8) and in major cognitive domains (knowing, applying, and reasoning at both grades 4 and 8). In addition, results for each grade are reported as the percent of students achieving at or above four international benchmarks (advanced, high, medium, and low). In conjunction with these achievement data, TIMSS also collects an array of contextual data about curriculum, instruction, school resources, and students from curriculum specialists, school principals, science teachers, and the students themselves in each participating country. These data, collected through a series of background questionnaires, provide important context for understanding and interpreting the science achievement results and improving teaching and learning in science in the participating countries.

TIMSS Advanced, a companion assessment of TIMSS, assesses the advanced mathematics and physics achievement of students who are enrolled in pre-university advanced mathematics and physics courses in their final year of high school. TIMSS Advanced was originally assessed together with TIMSS in 1995 to provide participating countries with a comprehensive picture of their mathematics and science education across primary, middle, and upper secondary schools. However, TIMSS Advanced was not assessed again until 2008, when a number of countries expressed interest in an advanced assessment due the strong link between specialized STEM expertise and economic productivity. In 2015, TIMSS Advanced again will be administered in the same year as TIMSS so that countries once again can gain a comprehensive view of STEM education from primary school through the entry to university-level studies. Also, in 2015, countries will have the option to administer TIMSS Advanced to students enrolled in advanced mathematics and physics courses in their first year of post-secondary study.

Both TIMSS and TIMSS Advanced are projects of IEA (the International Association for the Evaluation of Educational Achievement). Headquartered in Amsterdam, IEA has been conducting international comparative studies of student educational achievement since 1959. TIMSS, TIMSS Advanced, and PIRLS are directed by IEA's TIMSS and PIRLS International Study Center at Boston College.

The TIMSS Science Framework

The TIMSS science assessment is based on a comprehensive assessment framework that is developed collaboratively with the participating countries (Mullis et al. 2009b). The assessment frameworks for each new TIMSS science assessment are updated from those used for the prior assessment. Updating the frameworks on a regular basis provides participating countries an opportunity to review and provide feedback based on changes in science curricula in their countries and enables the framework and assessment to evolve gradually over time, while still maintaining the coherence from assessment to assessment that is required for reporting trend data.

The TIMSS science assessment framework for TIMSS 2011 consists of a content dimension that specifies the subject matter domains to be assessed in science and a cognitive dimension specifying the cognitive domains – the skills and behaviors that are expected from students as they engage with the science content. At grade 4, three major content domains define the science content: *life science*, *physical science*, and *earth science*. At grade 8, four major content domains define the science content: *biology*, *chemistry*, *physics*, and *earth science*. At both grade 4 and grade 8, the cognitive dimension was defined by three domains based on what students are required to know and do when engaging with the various items included in the TIMSS 2011 assessment: *knowing*, *applying*, and *reasoning*. Table 1 shows the target percentages of testing time devoted to each of the science content and cognitive domains in the fourth- and eighth-grade assessments.

In addition to defining content and cognitive domains, the TIMSS 2011 science assessment framework recognizes the importance of the *science inquiry* in the teaching and learning of science and specifies that science inquiry should be assessed in TIMSS in the context of the TIMSS science content domains and drawing on the full range of skills and behaviors defined in the cognitive domains. Thus, assessment items addressing aspects of science inquiry are included within both the content and cognitive dimensions of the assessment framework.

Third International Mathematics and Science Study (TIMSS), Table 1 Target percentages of the TIMSS 2011 science assessment devoted to content and cognitive domains at the fourth and eighth grades

Fourth grade		
Content domains	**Percentages (%)**	
Life science	45	
Physical science	35	
Earth science	30	
Eighth grade		
Content domains	**Percentages**	
Biology	35	
Chemistry	20	
Physics	25	
Earth science	20	
Cognitive domains	**Percentages**	
	Fourth grade (%)	**Eighth grade (%)**
Knowing	40	35
Applying	40	35
Reasoning	20	30

The TIMSS 2011 assessment framework also includes a contextual framework that specifies the information to be collected via TIMSS background questionnaires. The 2011 contextual framework encompasses four broad categories of contextual factors that affect students' learning in science:

1. National and community contexts (including country demographics and economic resources, the organization and structure of country education systems, and the science curriculum)
2. School contexts (including school size, location, and characteristics of the student body; school organization for instruction; school climate for learning; professional development opportunities for teachers; school resources; and parental involvement in education)
3. Classroom contexts (including teacher education and development; teacher gender, age, and experience; class size, instructional time, and class composition; curriculum topics taught; availability and use of instructional materials and technology; types of instructional activities; and types and uses of assessments)
4. Student characteristics and attitudes (including student gender and language spoken, family immigration status and socioeconomic background, and student attitudes toward learning science)

Information about these contextual factors was collected via background questionnaires completed by national-level curriculum specialists, school principals, science teachers, and the students who were assessed in TIMSS 2011. National-level curriculum specialists also provided a written description of science education in their country to provide information about the national contexts that shape the content and organization of the science curriculum as well as political decision-making processes that impact science education. These national contexts are compiled in the *TIMSS 2011 Encyclopedia*, Vols. 1 and 2 (Mullis et al. 2012).

The TIMSS science framework currently is being reviewed, revised, and updated for TIMSS 2015 and will be available by October 2013 at http://timss.bc.edu.

The Development and Administration of the TIMSS Science Assessment

The assessment framework provides the blueprint for the development of each TIMSS assessment. In each new assessment, in order to report reliable trends in achievement, approximately 60 % of assessment items are retained from prior assessments, with 40 % newly developed items completing the assessment. The assessment consists of approximately half multiple-choice items and half constructed-response items.

For each new assessment, approximately twice as many new items are developed as are needed for the final assessment. Item development is a highly collaborative process. The development of new items is guided by a science Subject Matter Item Development Committee, which includes science experts from participating countries. In addition, representatives from participating countries produce items at an item-writing workshop. All items undergo a rigorous review process by subject matter experts before being assembled into field test *block*s, each of which is approximately 20 min in length. Field test blocks are reviewed by representatives from participating countries and then administered in the countries approximately 1 year prior to the administration of the final TIMSS science assessment. Based on the results of the field test, field test blocks containing new items are selected and combined with blocks of items retained from prior assessments to complete the final assessment. The 2011 TIMSS development process is described in detail at http://timssandpirls.bc.edu/methods/t-instrument.html.

Prior to the administration of the final assessment, the assessment blocks and background questionnaires are translated from English into the numerous different languages of the participating countries. A rigorous translation verification process is utilized to ensure comparability among translated instruments. The final assessments are administered to carefully drawn probability samples of students from the target populations of fourth- and eighth-grade students in each country. Each country is responsible for carrying out all aspects of data collection and scoring, using standardized procedures. The methods and procedures for sampling, translation, and assessment operations used in TIMSS 2011 are described in detail at http://timssandpirls.bc.edu/methods/index.html.

Analyzing and Reporting TIMSS Science Results

The TIMSS science achievement scales are designed to provide reliable measures of student achievement across the trend cycles of the TIMSS assessments, based on the metric established with the 1995 data. Student achievement is summarized using item response theory (IRT) scaling methods, and for more accurate estimation of results for subpopulations of students, the TIMSS scaling uses plausible-value technology. In addition to the overall scales used to estimate student achievement in each assessment and to measure trends over time, IRT scales also are created for each of the content and cognitive domains described in the TIMSS science assessment framework. In addition, to describe what student performance on the TIMSS science achievement scales mean in terms of students' science proficiency, a scale anchoring analysis is conducted to describe and interpret student achievement at the advanced, high, intermediate, and low international benchmarks. The methods and procedures for scaling and scale anchoring are described in detail at http://timssandpirls.bc.edu/methods/index.html.

A comprehensive report of results from each TIMSS science assessment is released in the year following the TIMSS administration. The *TIMSS 2011 International Results in Science* can be accessed at http://timss.bc.edu/data-release-2011/index.html. For each participating country, the 2011 report includes overall achievement results for fourth grade and eighth grade along with trends in achievement for countries that participated in previous TIMSS assessments. The report also presents achievement differences by gender and trends in achievement differences. In addition, results are reported in relation to international benchmarks and for each major content domain and cognitive domain, along with trends in achievement for each of those reporting categories. Finally, the report presents achievement results in relation to the extensive set of contextual factors surveyed with the background questionnaires.

TIMSS Advanced Physics

TIMSS Advanced physics assesses the physics achievement of students in the final year of secondary school who have taken courses in physics and is the only assessment that provides information about the achievement of these physics students in an international context. The most recent TIMSS Advanced physics assessment in 2008 was based on a framework developed in cooperation with the countries participating in TIMSS Advanced (Garden et al. 2006). As in the TIMSS science framework, the TIMSS Advanced physics framework consists of a content dimension that specifies the subject matter to be assessed in physics and a cognitive dimension specifying the cognitive skills and behaviors that are expected from students as they engage with the science content. The four major content domains are *mechanics*, *electricity and magnetism*, *heat and temperature*, and *atomic and nuclear physics*. The cognitive dimension is defined by the same three cognitive domains as in TIMSS science: knowing, applying, and reasoning. The TIMSS Advanced framework currently is being reviewed, revised, and updated for TIMSS 2015 and will be available by October 2013 at http://timss.bc.edu.

Methods and procedures for development, translation, sampling, administration, scoring, analysis, and reporting for TIMSS Advanced generally parallel those for TIMSS and are described in detail in the *TIMSS Advanced Technical Report* (Arora et al. 2009). The results for the most recent administration of TIMSS Advanced are reported in the *TIMSS Advanced 2008 International Report* (Mullis et al. 2009a).

Cross-References

- ▶ Assessment Framework
- ▶ Assessment of Doing Science
- ▶ Assessment of Knowing and Doing Science
- ▶ Assessment: PISA Science
- ▶ Large-scale Assessment

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Transformative Science Education

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Keywords

Education for sustainability; Multi-paradigmatic research; Professional development; Socially responsible science education; Transformative learning; Transformative research

Education for Sustainability

How can we prepare science teachers with professional knowledge and skills for ensuring that teaching and curricula meet the global challenges of the twenty-first century, among which learning to live sustainably on planet Earth is one of our most pressing concerns? Education for environmental, cultural, and economic sustainability has been a key focus of the United Nations for the past decade, underpinned by the Brundtland Report's advocacy of an "intergenerational conscience" which recognizes that meeting the needs of the present should not compromise the ability of future generations to meet their own needs (UNWCED 1987). The recent "Rio + 20" United Nations conference on sustainable development ratified this view.

But implementing education for sustainability is no easy task especially in science education. It involves much more than the traditional delivery and acquisition of objective scientific knowledge and skills. The Australian government (DEWHA 2010) adopted a definition of education for sustainability to guide curriculum designers nationwide that emphasizes the development of higher-level abilities essential to becoming an effective citizen and change agent:

- Ability to explore and evaluate contested and emerging issues
- Ability to deal with complexity and uncertainty
- Ability to take action as an individual and as part of community
- Ability to gather evidence and create solutions

Science education for sustainability brings together science education, values education, and citizenship education (including peace education) to focus critically on the interaction between the "Big Three": (i) *environmental issues*, such as human-induced climate change and loss of biodiversity associated with exploitation of natural resources; (ii) *sociocultural issues*, such as loss of indigenous knowledge systems that were developed through prolonged adaptation to living sustainably within the natural world; and (iii) *economic issues*, such as the implications for the natural and social world of economic models premised on producing prosperity via unlimited growth.

For students to learn meaningfully and collaboratively about these twenty-first-century sustainability issues, it is necessary that they develop higher-level cognitive and social abilities, including critical reflective thinking, cooperative decision-making, empathic and compassionate understanding of self and other, ethical awareness and values clarification, and commitment to personal and social action. The capacity of science teachers to prepare students with these higher-level abilities depends on teachers themselves having developed the same abilities.

Thus, the professional development of twenty-first-century science teachers calls for a more global perspective that takes science teaching well beyond the traditional (narrow) curriculum focus on *what* and *how* (or "pedagogical content knowledge") to embrace a humanistic perspective on the ethical responsibilities of science education (the curriculum *why*) and the unfolding personhood of the student as a future citizen in a democratic society (the curriculum *who*). For such a perspective, we turn to transformative learning theory.

Transformative Learning

Transformative learning theory has its roots in the work of Jack Mezirow in the field of adult and continuing education which came to prominence in the 1990s. Mezirow (1991) drew on philosophers such as John Dewey and Jürgen Habermas to reveal how our "meaning perspectives" are subject to epistemic, sociocultural, and psychological distortions that restrict the way we make sense of our experience of the world. Thus, we have limited ability to participate fully as creative, communicative, and self-determining agents in the processes of democracy.

For Mezirow, the key to transformative learning is to engage discursively with others in reflecting critically on the presuppositions underpinning our values and beliefs. Critical reflection emancipates us from our ideological prisons, thereby enhancing our conscious awareness of ourselves, others, and the worlds that we co-construct. For Mezirow, the role of transformative learning in adult education is to prepare citizens as critical self-reflective thinkers capable of contesting taken-for-granted social norms and making ethical judgments that lie at the heart of the process of democracy.

Over the past 20 years, Mezirow's ideas have been applied by many transformative educators to a range of adult education and training contexts such as higher education, the workplace, and the community. His theory of transformative learning has been enriched and become more nuanced by embracing nonrational modes of thinking in which emotions, intuition, mindfulness, and inspiration have an important part to play. Transformative learning theory has been coupled with theories of society, consciousness, wisdom, globalization, feminism, culture, and so on, to generate compelling aesthetic, spiritual, psychological, and ethical perspectives on the role of adult education in helping to create a more equitable, peaceful, diverse, and sustainable world (Taylor and Cranton 2012).

One of the uniquely powerful aspects of transformative learning is the focus on expanding conscious awareness of our situatedness in the world or, to put it more simply, our understanding of who we are and who we might yet become, as both individuals and social beings (Morrell and O'Connor 2002). Such a transformation entails developing a heightened consciousness of the relationship between our outer (material) and inner (nonmaterial) worlds. Transformative learning involves using cognitive, emotional, social, and (for some) spiritual "tools" to reconceptualize and reshape this relationship. Based on this perspective, transformative learning comprises five distinct but interconnected ways of knowing:

- *Cultural-self knowing* (self-realization) involves coming to understand our culturally situated selves, in particular how the (mostly invisible) premises underpinning our worldview – our shared values, beliefs, ideals, emotionality, and spirituality – give rise to our cultural identities and govern our habituated ways of being in, making sense of, and relating to our social and natural worlds.
- *Relational knowing* (opening to difference) involves learning to connect empathically and compassionately with our true (nonegoic) selves, our local community, the culturally different other, and the natural world.
- *Critical knowing* (political astuteness) involves coming to understand how and why (political, institutional, economic) power has structured historically our social realities by creating seemingly natural categories of class, race, gender, vocation, intelligence, etc., and how this mostly invisible power governs (especially distorts) our lifeworlds, our relationships with others, and our relationship with the natural world.
- *Visionary and ethical knowing* (over the horizon thinking) involves us in creative, inspirational, and discursive processes of idealizing, imagining, poeticizing, romanticizing, meditating on, and negotiating a collective vision of what a better world could be like and, importantly, what a better world should be like.

- *Knowing in action* (making a difference) involves consciously developing our capacity to help make the world a better place, committing to making a difference, and taking action locally while thinking globally.

Research as Transformative Learning

The question arises as to how to engage science teachers in transformative learning in order to prepare them with the higher-level abilities to pass on to their students so that they learn to participate individually and collectively in complex evidence- and ethics-based decision-making processes about living sustainably in an increasingly crisis-ridden and uncertain world buffeted by competing (economic, political, sociocultural) interests.

In recent years transformative learning theory has been instrumental in retheorizing postgraduate educational research, resulting in a model of "multi-paradigmatic research design" (Taylor et al. 2012). Building on developments in social science research over the past 30 years, this Kuhnian revolution has broken the stranglehold of (but not rejected) the traditional positivist paradigm wherein objective ways of knowing rule. For creative researchers the door has been opened to a range of innovative, exciting, and empowering epistemologies that enable research as transformative learning to flourish. These epistemologies derive from research paradigms, some of which are relatively new to science education.

The *interpretive* research paradigm offers a social constructivist perspective on the researcher's endeavor to develop deep, contextual, and emergent understanding of the culturally different other, together with a reflexive process of deepening his/her own culturally situated self-understanding. Ethnographic, autobiographical, and narrative methods are used to explore the lived experience of the researcher and his/her coparticipants. A powerful interpretive methodology used by researchers to excavate their life histories and recover lost cultural capital due to centuries of colonization by the Western modern worldview is auto-ethnography.

The *critical* research paradigm arms the researcher with an epistemology of ideology critique aimed at identifying sociocultural myths (made powerful by their invisibility) that structure social reality and contribute to perpetuating social injustice, cultural exclusion, inequity, racism, sexism, ageism, scientism, etc. A methodology of critical auto-ethnography enables the researcher to work toward decolonizing his/her own lifeworld, and ultimately the lifeworlds of students and/or colleagues, in a creative endeavor to enhance self-realization, identity, and free will as a prospective agent of social and structural reform.

The *postmodern* research paradigm brings a Janus-like (or two-faced) perspective to science education research. One face looks toward a philosophical deconstruction of the premises of all claims to secure, or foundational, knowledge (such as "scientism"), while the other face wears the smile of constructive playfulness. Postmodern researchers draw on the Arts for new methods of reasoning and modes of representation. Literary and artistic genres, such as fictive writing, poetry, ethnodramas, and imagery, embody innovative logics for researchers to make sense of and portray their nonrational experiences of the ineffability of their social and natural worlds.

Multi-paradigmatic research designs provide powerful ways of engaging researchers in transformative learning about the underlying premises of science education (Taylor 2013).

"Big picture" questions become accessible, as befits a science education endeavoring to respond to unprecedented global challenges:

- Whose human interests are being best served and whose are being excluded by current science curricula and pedagogies? And why?
- How can science education embrace authentically the popular ethos of "science for all" if it does not embrace the "sciences of all"?
- Why does the paradigm of Newtonian science, with its "clockwork" (reductionist, deterministic, linear, materialist) view of the universe, continue to prevail in physical science curricula? And in shaping postgraduate research designs?

- What are the distinctively different underlying premises of the "new sciences" of chaos theory, complexity theory, quantum theory, relativity theory, superstring theory, biocentrism, creative evolution, etc., and how might they contribute to a revitalized science education that aims to develop in students the higher-level cognitive and social abilities required for addressing the great moral and ethical challenges of the twenty-first century?
- How can a "socially responsible" science education counterbalance the triumphalism of modern science and technology (which are much celebrated on popular TV) with a "radical humility" born of a deep understanding of the well-documented harmful side effects of the seemingly benevolent use of science and technology to improve the human condition: global warming, natural resource depletion, loss of biocultural diversity, nuclear radiation contamination, unregulated genetic engineering, proliferation of weapons of mass destruction, etc.?
- What human values currently govern the selection (and exclusion) of science curriculum content and pedagogies, how well are they justified, what is their use by date, are there better alternatives, how are they being canvassed, and by whom?

Coda

As a form of professional development for science educators, transformative learning is inherently democratic and empowering as it makes visible and subject to critical scrutiny the (academic and political) decision-making process and premises that govern (past and future) curricula developments in science education. Transformative learning commits professional science educators to "making a difference" by having their voices heard in forums that shape future science curriculum policy. Transformative learning equips science education practitioners with advanced knowledge and skills to develop students' higher-level abilities for committing to act in ways that seek to promote the diversity of life on Earth.

Cross-References

- ▶ Action and Science Learning
- ▶ Cultural Influences on Science Education
- ▶ Culturally-Relevant Pedagogy

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Transposition Didactique

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The concept of transposition didactique (didactic transposition) was first proposed by the French mathematics educator, Chevallard, in the 1980s, who first developed it in the context of mathematics education. To discuss it, let us start with a particular case. When the concept of force is listed in an official curriculum or is taught in high school, its meaning cannot be identical to the meaning of the concept of force in the physics community. From the perspective of didactic transposition, this difference is unavoidable.

To understand this claim we need to study how individuals or institutions understand and use an item of knowledge or, to approach it from another angle, the relationships that they construct with this knowledge. These relationships constitute the meaning of this knowledge constructed by the individuals or institutions. For example, if we take a group of engineers constructing a bridge, a group of physicists taking part in the construction of a space shuttle, a high school physics teacher, and a group of students, their ways of using the concept of force will not be the same. As a matter of fact, due to the different things that are at stake in the different situations, these individuals or groups will use the concept of force differently. Since, according to Chevallard (1989, 1991), the ways of using the concept of force are different, the concept necessarily has different meanings in each case, even if these meanings are compatible and may overlap.

When a country or a state develops a new curriculum or new standards, an official institution, most often the Ministry of Education, chooses groups of experts to design it. The members of these groups may belong to the institution itself or be nominated by it. Each group is in charge of a part of the curriculum, according to the disciplines taught in the country. In experimental sciences, the process might involve a single group or several groups depending on which disciplines are taught. In science, the curriculum is principally (perhaps even totally) designed with reference to the knowledge and practices of the scientific community. Sometimes, for example, when socio-scientific issues are included in the curriculum, the group can also use social knowledge and practices as references. The idea of didactic transposition makes explicit that there is an unavoidable difference/distance between the reference knowledge and practices and those involved in the curriculum or the standards.

This theoretical point of view therefore leads researchers to raise questions aiming to understand better how the transformation occurs and with what constraints. Two main steps of transposition are distinguished. The first step goes from the reference knowledge or practices to the curriculum. The second step focuses on the transposition from the curriculum to the classroom activity, which is mainly the responsibility of the teacher and of designers working from the official curriculum.

The Didactic Transposition from Scientific Knowledge to Official Curriculum or Standards

Institutions such as ministries of education are generally responsible for the step of transposition from scientific knowledge to official curriculum or standards. The products of this step are texts that present the knowledge to be taught. Note that here and in the following discussion, knowledge is used with a broad meaning that includes practices and epistemological aspects. These texts are usually structured according to the concepts, processes, or more recently societal uses of a discipline. This division into “objects of knowledge to be taught” is necessary and is different from those used in the scientific community. For example, the official curriculum in England for science at key stage 4 (14–16 years old, grades 10–11) (in its 2007 version) was divided into two main parts:

- How science works, with subdivisions: (1) data, evidence, theories, and explanations, (2) practical and enquiry skills, (3) communication skills, and (4) applications and implications of science.
- Breadth of science, with subdivisions: (1) organisms and health, (2) chemical and material behavior, (3) energy, electricity, and radiations, and (4) environment, earth, and universe. These divisions correspond more or less to the disciplines – life science, chemistry, physics, and earth science.

This division is not used in the activity of the scientific community. For example, in a typical published article, the methods, processes, and content are deeply related; similarly in laboratory activity, the researchers' practices integrate these two components. In contrast, in the curriculum, each part has autonomy; a given object of knowledge to be taught is developed for it in the text. Moreover, each part is developed as elements whose acquisition by the students has to be assessed. This corresponds to general characteristics of curricula or standards developed by Chevallard (1991). They are public texts identifying distinct objects of knowledge to be taught, the acquisition of which should be assessed. There are also three other characteristics: the knowledge to be taught is de-syncretized and its acquisition is sequential; it is depersonalized; and the sequence of students' acquisition of knowledge is planned.

De-syncretized knowledge: In the example of the official curriculum of England, in the part headed "How science works," one of the items is "how scientific data can be collected and analysed." Such an object of knowledge is not isolated in the practices of the scientific community; but, in the official curriculum, it is distinguished from other elements and becomes an item in the text of the curriculum. In other words, it is de-syncretized.

Depersonalized knowledge: The objects of knowledge are presented as independent of a person. This characteristic has been highlighted by educational researchers who discuss the role of history in science teaching. In the example presented above for England, this depersonalization is clearly done; the subheading is not "how scientists work" but "how science works."

Planned knowledge: The teaching of the objects of knowledge has to be planned. Moreover, at the level of a curriculum, this plan is implicitly supposed to be also the students' acquisition plan. This planning is also unavoidable. For example, the official curriculum is constructed at different levels from grade 1 to 12 (or 13 depending on the country); there is a planning according to the succession of grades. In addition, for each year the curriculum may propose a progression. The didactic transposition involves planning the sequence of the objects of knowledge; this planning can be more or less precise from case to case.

The Didactic Transposition from Official Curriculum or Standards to Teaching Practices

This transposition is up to the teachers and to the designers of teaching sequences or other teaching resources to the extent that they refer to the official curriculum. Of course teachers have many constraints to respect, such as allocated duration and school organization. However, this step of the transposition is crucial for students' outcomes. Nowadays, as we have already mentioned, most curricula involve practices, both scientific ones and, in some cases such as socio-scientific issues, societal ones. When practices are involved, the curricula specify objects of knowledge to be taught that include the type of teaching situations; this is not the case when science content knowledge is involved. In the latter case, the way these objects are introduced depends on the teaching strategies chosen by the teachers. They could be introduced using various strategies: traditional lecturing, problem solving in small groups with experiments or simulations, etc. In the case of practices as objects to be taught, the curriculum, more or less explicitly, specifies the types of teaching situations. For example, if the students should learn argumentation and not only the content of the arguments, the teacher should implement teaching situations where the students have to debate and produce arguments. Developing argumentation could also help students to learn how to argue and also the content of arguments. Similarly, introducing ideas about the nature of science can be made in diverse teaching situations such as discussing experimental results, designing experiments, constructing hypotheses, etc. These ideas can also be introduced together with new conceptual knowledge. In short, introducing diverse components of knowledge and scientific practices as objects to be taught makes teaching situations and their progression particularly complex to design. In the framework of didactic transposition, the teachers or the designers should carefully analyze the reference practices in order to choose among their components those that they want to teach and how they adapt them; thus, the unavoidable distance between the reference practices and those involved in teaching is recognized and analyzed. For example, the idea of authenticity sometimes proposed for enquiry teaching cannot lead to a simple reproduction of the practices of reference. The authenticity can only be partial.

The planning of the objects of knowledge is less complex when they are discretized and mainly content oriented. The teaching order is not always easy to choose, but the choices can be discussed; for example, voltage might be introduced first to characterize batteries, followed by current, or the reverse. However, when the objects of knowledge are components of practices rather distant from those of the students, such as scientific practices or even social debates, the planning is much more difficult. For example, the development of practices of debating in the science domain (which can include societal issues) can be associated with the development of conceptual understanding of other objects of knowledge or considered as a separate object of knowledge, and thus, additional teaching time is necessary. The introduction of practices to be taught constrains teachers to establish certain types of relationships with their students, for example, that different points of view should be accepted and taken into account in the classroom, that the dialogue between students is important, and so on. Hence, it may alter the didactic contract (contrat didactique) (Brousseau 1997) between the teacher and the students. Such changes in relationships cannot be introduced rapidly; the classroom practices take time to be modified. Planning involves delineating different elements of the knowledge to be taught at least for their introduction. For example, some components of energy might be associated with argumentation, whereas astronomy might be associated with the limits of science.

In sum, the didactic transposition is a theoretical tool to analyze and develop the official curriculum and also to implement the teaching practices.

Cross-References

- ▶ Constructivism
- ▶ Curriculum
- ▶ Didaktik
- ▶ Relevance
- ▶ Teaching and Learning Sequences

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Validity and Reliability of Science Assessments

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Keywords

Accuracy and appropriateness of score inferences; Technical quality of assessment; Test quality; Validity

Validity is the overriding concept describing assessment quality. It expresses the extent to which an assessment measures what it is intended to measure and provides sound data for an intended decision-making purpose. As described below, reliability conveys the consistency of a measure and is necessary but not sufficient for adequate validity. Strong evidence of both validity and reliability is required for high-stakes uses of science assessments. While evidence requirements are reduced, both also are concerns for classroom assessment purposes.

Validity Defined

Modern measurement theory defines validity as the degree to which evidence and theory justify particular interpretations and uses of test scores (see AERA, APA, & NCME 2014). Validity is not a unitary property of a test but rather is an evidence-based judgment that requires a variety of evidence to evaluate the accuracy of score inferences and the appropriateness of score use for particular purposes. A test may have high degree of validity of one purpose but not another. For example, scores from a science test may have a high degree of validity for identifying scientifically gifted students but have a low degree of validity for diagnosing learning needs.

Reliability, as noted above, is a necessary but not sufficient requirement for validity. Reliability refers to the consistency and precision of the scores, the extent to which they provide constant estimates of some stable attribute, rather than error. If a bathroom scale is reliable, for example, it will give you the same result regardless of where or when you stand on it, unless you have actually gained or lost weight. In contrast, if the scale is not reliable, your measured weight may change at each weigh-in, regardless of whether your actual weight has changed and so the validity of the measure is compromised. At the same time, a measure can be reliable, but not valid. Consider your scale is perfectly reliable, but if its zero mark is 5 lb off, it will provide inaccurate information. So too with test scores, if they contain too much error or are unduly affected by factors unrelated to the construct being measured, they cannot be trusted to provide accurate inferences.

R. Gunstone (ed.), *Encyclopedia of Science Education*, DOI 10.1007/978-94-007-2150-0,

Validity Argument

Evaluating the validity of an assessment for a particular purpose involves laying out an argument that links student performance on an assessment to the specific interpretations, conclusions, and/or decision that will follow from the given purpose (see Kane 2006). The argument is composed of a series of claims that require substantiation to justify the use. While claims must be differentiated depending on the intended purpose, claims generally have many of the following criteria (see Herman & Choi 2010):

- **Alignment**: Science assessments should be aligned with meaningful learning goals that integrate science content and practices, including rigorous levels of cognitive demand. Historically, many science assessments have focused on lower-level facts and explanations at the expense of assessing students' ability to engage in inquiry, communicate, and apply their knowledge to solve problems.
- **Learning/instruction value**: Recent theory suggests the value of basing assessment development on a model of how learning is expected to develop so that results can be used to evaluate where students are relative to a progression of expected learning and to diagnose their learning needs. Assessments that are cognitively expansive, that is, that ask students to explain or organize their knowledge not only directly support student learning but have diagnostic utility in exposing student thinking and possible misconceptions.
- **Fairness**: A fair assessment provides all students the opportunity both to learn what is expected and to demonstrate what they know. A fair assessment does not contain construct-irrelevant elements that may unduly advantage or disadvantage some students, for example, unnecessary linguistic complexity in science item that may disadvantage English learners or low-ability readers.
- **Reliability and precision**: Reliability and precision indices provide estimates of the score consistency (see above). For constructed response tasks, the reliability of scoring as well as scores must be examined.
- **Transfer and generalizability**: Assessments sample student performance from a larger domain of knowledge and skills and scores are useful to the extent that they represent student capability in the broader domain, and not just how students do on this particular set of test scores.
- **Instructional sensitivity**: Any use of assessment to improve teaching and learning assumes that scores are influenced by effective instruction and engaged learning and are not simply a function of student ability.
- **Comparability**: Scores often are used to compare or rank students, teachers, or schools and/or to evaluate progress from year to year. To serve this purpose, scores must provide equivalent or interchangeable measures of the same construct. This is one important reason that test procedures are standardized – so that differences in test procedures, rather than student ability, do not unduly influence students' scores. Further, it does not make sense to judge student progress by directly comparing test performance in a chemistry class to that in the physics class – it is an apples and oranges comparison.
- **Consequences**: Research suggests that assessment serves a strong signaling function in communicating what is important to teach and learn and in modeling expected practice. Good assessment supports productive changes in teaching, learning, and equity.

Types of Evidence

The Standards for Educational and Psychological Testing lays out four sources of evidence for documenting validity claims. These include evidences based on:

- Analysis of test content, for example, expert review of the alignment between test content and intended learning goals or of the assessment's instructional/learning value
- Analysis of response processes, for example, think-aloud protocols to examine whether students actually engage in inquiry to solve science problems that are intended as inquiry measures

- Psychometric analysis of internal structure, for example, whether the psychometric structure of the test, such as its dimensionality, is consistent with the test blueprint and reliability and precision indices
- Evidence based on relationships to other indicators, for example, the extent to which test scores generalize to other, respected measures of the same construct or predict future, related performance
- Evidence based on consequences, for example, evidence substantiating that intended benefits of testing are realized, for example, that tests meant to improve science teaching and learning actually do so and the extent to which test-based decisions support subsequent success

Evaluating assessment validity starts with a clear definition of intended goals (constructs) and the purpose the test is intended to address and involves the integration of a variety of evidence supporting important claims and criteria (see Mislevy et al. 2002). The alignment of the test with intended learning goals is often a first issue that typically starts with expert review of test content during the test development process, may involve analysis of students' response processes during pilot testing, and is supported by psychometric analysis later in field testing or operational use of the test. Or another example, evaluation of fairness too starts with an expert review of test content to identify item characteristic or content that may unfairly advantage or disadvantage students from diverse subgroups, draws on psychometric analysis of differential item functioning, and is sensitive to the consistency of empirical relationships and consequential evidence for student subgroups. Test publishers and sponsors are responsible for providing validity evidence for their tests, and it should be found in the technical manual.

Validity and Classroom Assessment

While it is important that there be strong evidence of validity for tests that will have important consequences for students, teachers cannot be expected to develop such evidence for their classroom tests. Nonetheless, validity criteria provide important touchstones for teachers as they develop and use tests – for example, is the test aligned with and do the items well reflect the depth and breadth of intended science learning goals? Have students had the opportunity to learn what is being assessed? Is the test fair to all students? Will it provide value for instruction and learning? Is my scoring reliable – or were papers reviewed earlier scored differently than those scored later?

Cross-References

- ▶ Alignment
- ▶ Assessment Framework
- ▶ Assessment: An Overview
- ▶ Instructionally Sensitive Assessments (Close, Proximal, Distal Assessments)

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Values

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Keywords

Ethic; Moral; Science education

It is clear from many studies that students' interest in science, mathematics, and technology declines as grade levels increase. Another alarming issue is recruitment of students for STEM-related careers. According to the ROSE Project results, extremely few girls wish to become scientists, and even for boys, the percentage is low. Even in Europe, only about 50 % of boys gave a positive response to the question: "I would like to get a job in technology," but very few girls indicated that they would like to pursue such a career option (Sjøberg and Schreiner 2010). These kinds of results from project reports highlight the urgent need for more effective action on the teaching and learning of science in schools (Cavas 2012).

A critical aspect of science education is the values of science education. A value can be defined as individual belief on a moral or ethical issue. Values have major influence on a person's behavior and attitude and serve as broad guidelines in all situations (Business dictionary 2013). In most science education curricula, the aim is not only to produce scientists but also to empower all citizens with the knowledge, skills, and values they need to live and work successfully in an increasingly technological-knowledge-based society (Tang 2013; Character Development Forum 2013). The latter in particular requires the valuation of science. The values in science, however, are not so different from values in general: valuing objectivity, accuracy, precision, pursuit of truth, and problem-solving; valuing human significance, the protection of human life, and balancing safety and risk; valuing intellectual honesty and academic honesty; valuing courage and humility; and valuing decision making and willingness to suspend judgment. More scientific-oriented values include valuing logic, evidence, and verification and valuing integrity, diligence, persistence, curiosity, open-mindedness, critical evaluation of alternatives, and imagination (Character Development Forum 2013).

There are also some concerns about negative values in science education: misuse of science and hidden values. The negative values in science education might have an important impact on a students' science achievement. Negative values, like a disrespectful interaction between a teacher and student, treatment of student opinions in a disrespectful way, and "right answer" syndrome, may be harmful to young students who are easily influenced. Students influenced by negative values in science classroom often have problem to achieve science courses and negative attitudes toward science.

Cross-References

- ▶ Cultural Values and Science Education

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Values and Indigenous Knowledge

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Keywords

Science education in the non-west

A fundamental attribute of Indigenous Knowledge is that it is place based (Cajete 2000); therefore, the values tied to much of the knowledge are also place specific. However, Indigenous people also share commonalities in their

Indigenous ways of understanding how to live. The commonalities are discussed in the following paragraphs.

The term "coming-to-know" or "coming-to-knowing" is used to describe the process of developing understandings in Indigenous Knowledge (Cajete 2000; Peat 1994). The term means to live properly in ones community and in nature, which includes the "action of living in harmony with the natural environment for the sake of the community's survival" (Aikenhead and Michell 2011, p. 69). "Coming-to-know" reflects the idea that understanding is a life-long journey, or process, or quest for knowledge (Cajete 2000). Learning, from an Indigenous perspective, is an experience that seeks balance in mental, spiritual, emotional, and physical ways.

The importance placed on life-long, balanced, and experiential learning in Indigenous cultures influences what is valued by Indigenous societies. Elders pursue "wisdom-in-action as lifelong learning and as advice for a community's survival" (Maryboy et al. 2006, p. 9). Indigenous wisdom is intimately related to human action based on natural laws. Some have described this as the relational attribute of Indigenous Knowledge (Aikenhead and Michell 2011), where everything in nature, including humans, enjoys equal status and humility is a cherished value. The relational attribute of Indigenous Knowledge also includes the value of respect.

In addition to values associated with the relational attribute, the values inherent in Indigenous Knowledge have been described in terms of competencies that reflect an ability to survive in a real-world context (Barnhardt and Kawagley 2005). The competencies valued by Indigenous society would be those associated with providing for your family and community such as hunting, fishing, and preparing hide.

Cross-References

- ▶ Cultural Values and Science Education
- ▶ Indigenous Knowledge Systems and the Nature of Science
- ▶ Teacher Preparation and Indigenous Students

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Values and Learning Science

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Keywords

Creativity; Curiosity; Empiricism; Open-mindedness; Parsimony; Rational thinking; Skepticism; Values

Halstead (1996) has provided a definition of values that places them as life-guiding principles (see also "Curriculum and Values"). In learning any discipline, including science, there are certain rules or paradigms that must be followed, and consequently any discipline is underpinned by values. Many of these values are discussed in "Curriculum and Values." When learning science, students need to be aware of these values and their significance when learning science and differences with values in other disciplines they are learning. For example, rational thinking in science and mathematics may be partly similar whereas empiricism gives science one of its unique values and qualities.

The inclusion of Nature of Science as a fundamental part of learning science means that the values that underpin science are often more explicit in terms of learning than they are in many other disciplines such as mathematics. However while the articulation of such values may be explicit when focusing on the Nature of Science, how teachers interpret such values and promote their development within science classrooms is often less obvious. For example, where are the opportunities for students to develop an understanding of creativity and parsimony in the science classroom? In providing some definition around values that are essential components of learning science, teachers may be able to encourage students to gain an understanding of how these values underpin science. Some definitions of values central to science and therefore science learning that are often not explicitly considered in learning science are now provided.

Parsimony

When there are competing explanations (hypotheses, models, systems, etc.), the simplest explanation, model, or system that accounts for most of the data is accepted for use.

Note: The term "parsimony" is derived from the Latin lex parsimoniae which broadly translates as the law of parsimony, law of economy, or law of succinctness. In more recent times, the phrase Ockam's razor has been used to describe this value of science. The razor is a principle that suggests we should tend towards the simplest explanation until such simplicity of explanation can be substituted for greater explanatory power. Its (the razor's) value lies in the justification of deciding between the competing explanations. Such justifications need to also take account of the plausibility, fruitfulness, and robustness of such explanations.

Curiosity

Curiosity relates not only to the questioning but also to consideration of the wonder and mystery that is aroused when attempting to provide explanations for phenomena that occur in the natural world.

Creativity

Creativity, particularly in thinking, is characterized by its apparent lack of connection to other ideas. Processes such as "random thoughts," "thinking outside the box," "guesses," and "intuition" are often attributes of creativity. In attempts to promote the creative process, it is important to not place parameters around thinking.

Open-Mindedness

Open-mindedness means being receptive to the alternative and different ideas and opinions presented by others. It is also attributable to looking at data in alternative ways.

Rational Thinking

Rational thinking or rationality describes the cognitive process of reason, how one thought links to another. Rationality is different from logic in that it focuses on the notion of reason as a type of thought. Logic, on the other hand, is a process that attempts to describe the norms and rules by which reasoning operates and in this way can attempt to teach orderly thinking. Logic is one type of rational thinking. For example, rational thinking would include such things as skipping steps, working backwards, and drawing diagrams, which are not part of logic.

Empiricism

Empiricism relates to knowledge that is derived from sensory experience (and includes direct and indirect observation). In this sense, it provides an alternative view to rationalism on the processes of knowledge creation, as rationalism is based on reason or thought. The power of these two seemingly opposing theories on knowledge creation is in recognizing their differences and making judgements based on the differences.

Skepticism

Skepticism relates to a general attitude of doubt or questioning of knowledge, opinions, and beliefs presented as facts or claims that are made. Skepticism in science is often seen in the practice of subjecting beliefs and claims to scientific investigation (and further scientific investigation) in order to supporting their reliability.

This list of values is not complete. It focuses on only some of the epistemic and sociological dimensions of values of science. Providing such definitions of fundamental values gives learners of science an opportunity to appreciate the attributes of science as a powerful way of knowing and acting. Other values such as interdependence (on other scientists and their research) and community practice also need to be fostered when students learn science.

Cross-References

- ▶ Curriculum and Values
- ▶ Discourse in Science Learning
- ▶ Imagination and Learning Science
- ▶ Interests in Science

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Values and Western Science Knowledge

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The central question regarding the relationship between science and values is whether science is value-free or not. The doctrine of value-freedom, which should be understood as an ideal rather than a reality, is based on a categorical fact-value judgment distinction, according to which no value judgments can be derived from facts. It then states that the business of science is to discover facts about the world, not to pass any value judgments; that science is neutral with respect to social, political, and moral values and therefore can serve any such values; and that scientific theories and claims should be accepted or rejected on empirical-evidential grounds, not on social, political, moral, and religious considerations (Lacey 1999). The ideal of value-free science, an early formulation of which is owed to Bacon and Galileo, dates back to the great Scientific Revolution in Europe in the sixteenth and seventeenth centuries and remains especially popular among scientists today.

Contemporary versions of the doctrine of value-freedom distinguish between epistemic and non-epistemic (social, political, economic, moral, religious, and personal) values and recognize the role of the former in scientific inquiry. Epistemic values typically include truth, quantitative accuracy, testability, explanatory power, fruitfulness, unification, internal and external consistency, simplicity, and the like, though currently there exists no consensus about this list. For example, social constructivists and instrumentalists shun truth, feminist philosophers of science prefer novelty (as opposed to external consistency), ontological heterogeneity (as opposed to unification), complexity (as opposed to simplicity), and applicability as important epistemic values (Longino 1996). Epistemic values also function as criteria for theory choice: other things being equal, a theory which exhibits an epistemic value is better than another which lacks it. In the light of the distinction between epistemic and non-epistemic values, the doctrine of value-free science can be formulated more accurately: non-epistemic values should play no role in scientific inquiry; any “outside” interference with the workings of science has devastating effects on scientific progress and objectivity, as exemplified by the Galileo and Lysenko affairs.

As stated, the ideal of value-freedom does not do justice to the role of non-epistemic values. To begin with, the sustained pursuit of science by whole communities of scientists in a society itself reflects a positive value orientation to science: scientific investigation of the world is considered to be a worthwhile enterprise in that society because it is believed to yield reliable knowledge. This valuing of science is not epistemic, but social (Douglas 2009). Clearly, epistemic values contribute to the production of such knowledge. But so do some non-epistemic values. To see this, we must note that science is not just an epistemic system of thought and activity, but is at the same time an institution with its own social and ethical values and norms, which refer to certain attitudes scientists are expected to adopt and display in their interactions with fellow scientists as well as in carrying out their scientific activities. These include Mertonian norms of universalism (scientific claims should be evaluated according to preestablished objective criteria so that characteristics of scientists such as ethnic origin, nationality, religion, class, and gender are rendered irrelevant), organized skepticism (scientists should subject every claim to logical and empirical scrutiny on the basis of clearly specified procedures that involve scientific reasoning, testability, and methodology), and disinterestedness (scientists should evaluate and report their findings independently of whether they serve their personal or national interests, ideologies, and the like). Also among the non-epistemic values already present in the institution of science are intellectual honesty or integrity (scientists should not fabricate, distort, or suppress data), respect for research subjects and the environment (scientists should treat human and animal subjects with respect and dignity and avoid causing harm to the environment), freedom (e.g., scientists should be free to pursue any research, subject to certain constraints, as implied by the previous two values), and openness (scientists should be open to free and critical discussion and to share ideas, data, and techniques and be willing to change their opinion when presented with good reasons) (Resnik 2007). That these ethical and social values (with the possible exception of respect) function to produce reliable and objective knowledge needs no argument.

Non-epistemic values play a direct role in the choice of scientific problems and research programs as well. For example, the search for cures and more effective treatment of diseases, techniques of better crop yield, and more efficient means of energy production may no doubt be motivated by intellectual curiosity, but they also reflect the value of human life and of the reality of a competitive economy. It is a well-known fact that scientific research costs money and that, therefore, the direction of research is influenced greatly by funding decisions. The role of such ethical, social, and economic values in science is widely acknowledged and deemed acceptable even by the defenders of the doctrine of value-freedom. In short, not all influences of non-epistemic values on science are necessarily damaging to the progress, reliability, and objectivity of science.

Science is, to varying degrees, value laden in its social organization, language, methods, and even theories. Women and ethnic minorities are often excluded, underrepresented, or marginalized in scientific institutions. Such terms and phrases as “adaptation” and “survival of the fittest” in biology are laden with positive value (Graham 1981). Feminist scientists and philosophers have documented sexism and androcentrism in experimental design in medical sciences and theories about sexual reproduction, menstruation, and heart disease (Kourany 2010). To the extent that non-epistemic values cause bias in science and jeopardize the objectivity of its findings, these cases can be interpreted as a strong reason for protecting the ideal of value-freedom. They invite revising the institutional structure of science, methods, and theories of science rather than rejecting the ideal of value-freedom.

The crucial question is whether non-epistemic values have any legitimate place in accepting or rejecting scientific theories. The demand that theories be accepted or rejected on the basis of evidence and scientific reasoning seems unobjectionable, and proponents of the ideal of value-freedom claim that the intrusion of any non-epistemic value in this context would destroy the whole stature of science, turning it into a battlefield of societal forces. Critics argue that since no amount of evidence can verify a theory completely, the scientist must decide whether the evidence at hand is strong enough to warrant the acceptance of the theory in question. But this decision will depend on weighing the pros and cons of making a mistake, i.e., accepting a false theory or rejecting a true one. This weighing would typically involve considering, among other things, the ethical and social consequences of one's decision, which would then amount to a value judgment (Rudner 1953). Hence, the argument goes, non-epistemic values necessarily play a role even in the context of theory acceptance and rejection, but this would not make science less objective if scientists explicitly state the non-epistemic value considerations they employ in their decisions. If anything, it would make science more objective by opening up such considerations for public discussion.

A similar conclusion is reached through the argument from underdetermination. Theories are often underdetermined by evidence at hand, and since a collection of data counts as evidence for or against a theory only relative to certain background assumptions, a change in the latter amounts to a change in the evidential relations (Longino 1990). As an example, consider the phenomenon of stellar parallax predicted by the Copernican theory. Seventeenth-century astronomical observations failed to detect any such phenomenon. Whether this counts as a disconfirmation of the Copernican theory or not depends on the background estimation of the distance between the star and the Earth. No doubt, background assumptions cannot be chosen arbitrarily, but sometimes it so happens that even mobilizing non-evidential epistemic values such as fruitfulness, explanatory power, and the like is of no help. This creates some space for scientists to pick those background assumptions that are in line with the social, political, ethical, or whatever values they favor, at least until new evidence kicks in (Anderson 2011). In this way, non-epistemic values may play a role in theory acceptance and rejection.

If the ideal of value-free inquiry is flawed, what is to replace it? A promising alternative is "social value management," which welcomes non-epistemic values into science, provided they are all publicly subjected to rigorous critical scrutiny by taking into account all perspectives (Longino 2002).

So far the discussion has focused on whether and, if so, how non-epistemic values influence science. It should be noted that their influence runs in the other direction as well. Just as societal values enter into science, science impinges on social, political, ethical, and religious values in various ways. To give a few striking examples, the Copernican revolution caused an upheaval about the place of human beings in the universe. Findings in the fields of physics, geology, paleontology, and evolutionary biology regarding the age of the Earth and the origin of humans clash with certain religious interpretations of sacred texts, questioning deeply held beliefs about what it is to be a human being. Environmental science teaches the value of respect for the natural world by showing how fragile our biosphere is, a knowledge that has implications regarding patterns of production and consumption. To the extent that science drives medical technologies (e.g., think about gene therapy, genetic enhancement, and cloning), it raises all sorts of questions about their regulation, how their benefits will be distributed in society, and who will pay for them, not to mention questions about the limits of human capabilities, the meaning of life and death, and what it means to lose loved ones especially if human cloning is allowed one day.

Cross-References

- ► Curriculum and Values
- ► Science Education in the Non-West
- ► Values in Science

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Values in Science

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Science is a combination of testable and certifiable, well-accepted, reliable knowledge about the physical world. Science has many epistemic values such that science should be conducted by scientists using systematic, validated, and well-accepted research methods (Allchin 1998; Allchin 2012). Scientific epistemic values include simplicity of concepts and heuristic testability, accuracy, precision, reliability, and generality (Allchin 2012). Scientific values involve a preference for the *simplicity of concepts* over complexity (Allchin 2012). Scientific conjecture must be testable in some way. Testing must involve *accuracy* and *precision*, measured values must be proximate to reference values, and measurement must be reproducible. *Reliability* suggests that the repetition of experiments should yield the same results (Allchin 2012). It is important that *generalizations* can be drawn from results. Moreover, scientific values include *ethics* given that science can never be disassociated from society and culture (Merton 1973; Allchin 1998; Allchin 2012).

Cross-References

- ▶ Cultural Values and Science Education
- ▶ Curriculum and Values

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Visitor Studies

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Although there is no uniformly accepted definition of visitor studies, it can be described as encompassing the broad range of research investigations conducted in order to better understand the behaviors, attitudes, interests, motivations, and learning of individuals who visit informal/free-choice educational settings such as museums, parks, nature centers, zoos, and aquaria. Another name often used as a synonym for visitor studies is audience research.

Consistent with a lack of agreed upon definitions, there are equally no agreed upon goals or parameters defining what should or should not be included as falling within the purview of visitor studies, though some ideas have been put forward. For example, the American Association of Museums' Standing Committee on Audience Research and Evaluation has suggested a particularly narrow scope for visitor studies saying that it refers to "the process of systematically obtaining knowledge from and about museum visitors, actual and potential, for the purpose of increasing and utilizing such knowledge in the planning and execution of those activities that relate to the public" (CARE 2012).

Taking an evaluation perspective, Bitgood (1988) asserted that visitor studies involves four fundamental assumptions:

1. *Visitor advocacy is the primary mission*: That input from visitors should play a major role in the design of both exhibitions and programs; the assumption being that traditionally this has not been the case.
2. *Multidisciplinary view*: That visitor studies is a devise for including a mix of viewpoints and expertise by b1ringing together specialists from exhibition design, education, visitor services, marketing, recreation, and evaluation.
3. *Formal evaluation*: That visitor studies represents a technique for answering questions about the effectiveness and efficacy of exhibitions and programs.
4. *Scientific*: The visitor studies approach utilizes a scientific model of collecting information about visitors and a scientific model of theory building borrowed from disciplines like psychology, sociology, education, and marketing to formulate empirically based principles of visitor behavior and learning.

Similar themes can be found in the definition proposed by the Visitor Studies Association (VSA), a professional organization dedicated to visitor studies. The VSA argues that visitor studies is an "interdisciplinary study of human experiences within informal learning environments. The systematic collection and analysis of information or data to inform decisions about interpretive exhibits and programs" (VSA 2012). They go onto say that visitor studies must always meet three criteria:

- Visitor studies follows rigorous research methods that adhere to the standards of the social sciences.
- Visitor studies draws from and contributes to the theory and practice of social science.
- Visitor studies is designed to improve the practices of learning in informal environments.

These three criteria are probably more aspirational than descriptive of the current state of visitor studies as there are numerous examples of studies, including published works, that fail to meet one or more of these criteria.

Brief History of Visitor Studies

Historically the vast majority of visitor studies research has been evaluative in nature, and most of the individuals calling themselves visitor studies professionals have been evaluators. Much of the original visitor studies research though could be classified as falling within the domain of basic research. With ever-increasing frequency in the past decades, this is again true. The number of published visitor studies research, as opposed to evaluation, investigation has grown by roughly 500 % over the past quarter century (Falk et al. 2012). Systematic, empirical investigation of visitors to informal/free-choice settings began roughly 100 years ago. Some of the earliest known visitor studies research by Eugene Robinson (1928) and his student Arthur Melton (1935) focused on visitors' behaviors and fatigue surrounding their viewing of art museum exhibits. However, it was not until the late 1960s and 1970s that visitor studies research began in earnest.

Early investigators and important exemplars of their works include Harris Shettel (1968), Chan Screven (1969), Roger Miles (Miles and Tout 1978), Minda Borun (1977), John Falk (Falk et al. 1978), and Robert Wolf (Wolf and Tymitz 1979). Starting in this period, the focus of visitor studies began shifting strongly from questions designed to develop generalizable understandings of visitors within informal settings to more evaluative questions related to assessing the efficacy of exhibitions and programs. It was also during this period that the first qualitative methodologies began appearing within visitor studies, originally as part of evaluation studies. This approach was initially quite controversial in the field and was considered by some as lacking the rigor and value of traditional quantitative, hypothesis testing approaches.

Although the quantitative-qualitative debate did not completely disappear during the 1980s and 1990s, the ranks of investigators conducting visitor studies grew considerably as did the number of methodologies employed. An ever-growing list of researchers began to investigate the behavior and learning of visitors across multiple settings, but increasingly the venue for these investigations was science-rich settings. Notable in this group of new investigators and some key examples of their work were individuals like Steve Bitgood (Bitgood and Patterson 1995), Judy Diamond (1986), Ross Loomis (1987), Beverly Serrell (1998), John Koran (Koran et al. 1988), Lynn Dierking (Dierking and Falk 1994), Gaea Leinhardt (Leinhardt et al. 2002), Paulette McManus (1987), Léonie Rennie (Rennie and McClafferty 1995), and Ben Gammon (1999). Although most of the individuals above could be considered basic researchers, the boundaries between research and evaluation became increasingly blurred in this period. Table 1 summarizes the contributions of these early researchers.

During the first dozen years of the twenty-first century, research has continued to expand to include many more investigators and a much wider diversity of topics and approaches. Historically published studies were scattered across a wide range of journals leaving individuals interested in this topic to their own wiles to find relevant research. Beginning around the turn of the new century, several new journals and/or sections of established journals were established specifically for this kind of investigation. Three particularly noteworthy examples include the journal *Visitor Studies*, the special section *Learning in Everyday Environments* of *Science Education* and the *International Journal of Science Education, Part B: Communication and Public Engagement*.

Current and Future Trends

Visitor studies remains a new and emerging field. Widely accepted paradigms and venues for publication remain an issue. Research of every variety is currently conducted representing a wide diversity of theoretical perspectives, with every imaginable type of methodology and data collection strategy utilized. At the same time, there continues not only to be work along the entire evaluation to research continuum but a widespread confusion amongst both researchers and practitioners about where the boundaries between these different forms of investigation lie, or even whether a distinction should be made. At one level this is typical of a young and emerging field still trying to find its center. It could be argued that this lack of focus is a good and healthy thing since it encourages broad thinking and multiple points of view. Alternatively, there are those who believe it is time for the field to determine a dependable suite of models, frameworks, and consistent metrics that can serve as an intellectual foundation on which to build future research and understanding.

Like many areas of the social sciences in the twenty-first century, there exist considerable tensions amongst investigators with differing paradigmatic perspectives. Individuals with more cognitivist leanings look askance at those who approach problems from a sociological or sociocultural perspective. The tensions between quantitative and qualitative researchers remain; though most investigators publicly express tolerance for diverse methodologies. And lurking in background of these more philosophical concerns lie the tensions within the community between those who believe that the goal of visitors studies should primarily be evaluative, directed toward short-term improvements in the quality of exhibitions, programs, and practices and those who are more theory driven and who are less concerned about immediate usability. Though not totally, these two camps roughly divide

Visitor Studies, Table 1 Summary of key historic works in visitor studies

Reference	Purpose	Methodology	Key finding(s)
Robinson (1928)	Research	Quantitative	Series of studies of art museum visitors, both in museums and in laboratory setting. Robinson found that size of the object or picture, its position on the wall, and the density of objects or pictures were all important factors in determining visitor attention
Melton (1935)	Research	Quantitative	Melton also focused on art objects in museums. He found that every object competes with other objects and that position/location of art objects influenced visitor attention
Shettel (1968)	Evaluation	Quantitative	Focused on criteria for judging exhibit quality using quantitative measures like "attracting power" and "holding power"
Screven (1969)	Evaluation	Review	Outlines front-end, formative, remedial, and summative evaluation and provides overview of techniques for designing and implementing these evaluations
Miles and Tout (1978)	Evaluation	Quantitative	Pioneering UK study of the "Human Biology" exhibition at the Natural History Museum; also a description of the new approach to exhibition design
Borun (1977)	Evaluation	Quantitative	A pioneering pilot study of museum effectiveness using a range of measures
Falket al. (1978)	Research	Quantitative	Investigation of how learning on school fieldtrips is influenced by a child's prior familiarity with the physical setting
Wolf and Tymitz (1979)	Evaluation	Qualitative	One of the first qualitative/descriptive evaluation studies of visitors
Bitgood and Patterson (1995)	Research/ evaluation	Review	Summary of research on exhibit design and its influence on visitor behavior; summarizes key points
Diamond (1986)	Research	Qualitative	Documented the influence of children on the viewing behaviors of family groups and the importance of parent–child interactions
Loomis (1987)	Evaluation	Review	Handbook of techniques and approaches for designing and implementing exhibition evaluation
Serrell (1998)	Research/ evaluation	Quantitative	Meta-study of dozens of visitor tracking and timing studies to determine generalizations about dwell time in exhibitions; most visitors view less than half of the elements in most museums' exhibitions
McManus (1987)	Research	Qualitative	Detailed investigation of visitor conversations. Although conversations were influenced by exhibit labels, they also tended to be quite focused on personal interests and concerns
Koran et al. (1988)	Research	Quantitative	Research showing that visitors are strongly influenced by observing the behaviors of other visitors, which they often try to emulate
Dierking and Falk (1994)	Research	Review	Broad review of the family behavior and learning literature; summarizes key points
Leinhardt et al. (2002)	Research	Qualitative	A summary of a collection of studies of visitors to museums utilizing a sociocultural framework
Rennie and McClafferty (1995)	Research	Review	Synthesis of research about learning in interactive science-related museums that concludes that visits do provide valuable motivational opportunities and generally impact student learning
Gammon (1999)	Evaluation	Review	Summary of research on exhibit design and its influence on visitor learning and behavior; summarizes key points

along professional lines with the former camp dominated by those who work primarily within or consult for informal institutions such as museums, science centers, zoos, and natural parks and the latter camp dominated by university academics housed in schools of education or psychology departments. Although it is too early to know whether the end result will be a fission into two distinct camps or some hybrid between the two, it is probably reasonable to predict that these tensions will ultimately need to be directly resolved.

The other trend that is likely to have a long-term impact on visitor studies is the growing pressure to minimize the distinctions between learning in and out of school (e.g., Falk and Dierking 2010; Stocklmayer et al. 2010). As the boundaries between formal and informal/free-choice learning diminish, so too will the boundaries between what constitutes the learning and behaviors of "visitors" and "students," as well as the theories and frameworks that currently divide those who investigate formal and informal settings. That is not to say that there are no differences between learning experiences in these settings. The importance of the physical and sociocultural context means that the unique affordances of experiences in settings like museums, zoos, nature centers, and the like will always require the need for methods and approaches that are specially tailored to these settings. However, it is quite likely that increasingly the distinct underlying theories and questions that currently separate visitor studies investigators from, for example, those who investigate learning in school classrooms, will become ever more blurred, if not largely disappear. The bottom line is that in the future, there will be an inexorable trend toward seeing learning as not rigidly bounded by time or setting. This will undoubtedly impact the direction of visitor studies as a field as well as those who conduct research under this umbrella.

Cross-References

- ▶ Aquaria
- ▶ Botanic Gardens
- ▶ Museums
- ▶ Planetaria
- ▶ Zoological Gardens

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Visitors, Research on

► Visitor Studies

Visualization and the Learning of Science

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Keywords

Levels of representation; Meta-visual capability; Multiple representation; Representation

Representation, Visualization, and Models

In general terms, a representation is anything that recalls an entity to mind for either the verbal description or the actual portrayal of it. Visualizations are a major subset of representations, consisting of those that are actually perceived by the eye ("external representations") or imagined in the mind ("internal representations"). Although still a matter of controversy, the only representations that are not usually classified as visualizations are words, whether spoken or written.

The goal of science is to produce explanations of the world as experienced. A model is a representation of a phenomenon in the world as experienced that is produced to enable specific types of explanations of it to be created (e.g., what causes it?). A model can be a representation of a material entity (e.g., the heart), an abstraction treated as if it were a material entity (e.g., energy), a system (e.g., a railway network), an event (e.g., an athletics meeting), or a process (e.g., an industrial chemical plant) (Gilbert and Boulter 2000). In short, models are an essential ingredient of all thinking and have a central role in scientific methodology. The visualization of models enables them to be thought about and to be manipulated and their explanatory capabilities explored. Given their importance, it is not surprising that a wide variety of modes, or types, of representation have been devised and used in science education.

The Modes and Codes of Visualization

Visualizations, as external representations, can be grouped into four broad modes – the material, the visual, the symbolic, the gestural – for all of which sight is the main medium of access. Each of these is characterized by its capacity to emphasize particular aspects of the models it is used to depict. Each mode will depict, in some way and to some extent, the entities of which a model is thought to consist, the angular relation between those entities (i.e., the distribution of those entities in three dimensions), and the distances between them and, in many cases, time and causality. This characterization is not a simple process, for each of these broad modes has spawned sub-modes in which the representational emphasis is somewhat different. Taking the four broad modes in turn:

The Material Mode

This mode consists of solid materials (e.g., metals, wood, plastics) used to create a representation of the three-dimensional structure of a model. As the result can be explored by touch, the mode is widely used in the initial phases of a scientific enquiry and throughout all phases of science education. The mode is very versatile, for example, in chemistry, the “ball-and-stick” genre can represent 3D crystal structures; in physics, the “blown-up” genre can represent the structure of electrical devices; and in biology, the “cut-away” genre can be used to depict the layout of organs in the body of an animal.

The advent of the large memory store personal computer has lead to the development of programs which generate virtual versions of material mode visualizations. The 3D nature of the original is indicated by visual clues, e.g., shading to show relative distance. While these virtual visualizations have the great advantage of being very easy to access at any time, the lack of the tactile aspect does limit their value to some extent.

The Visual Mode

The visual mode exists in many sub-modes, collectively known as “diagrams.” The most commonly used taxonomy of diagrams divides them into three groupings: “iconic diagrams,” in which both the entities in the parent model and all their spatial relations are retained (e.g., pictures, line drawings); “schematic diagrams,” in which the entities are reduced to abstract symbols but their spatial relations are retained (e.g., linguistic trees, Venn diagrams); “charts and graphs,” in which the entities and their spatial relations are all replaced by abstract concepts, e.g., line graphs and pie charts. In practice, these groupings are not adhered to diagrams in textbooks often consisting of mixtures of them. Diagrams are widely used to augment text in science education; however, students must become acquainted with their “codes of representation,” i.e., the way that they depict the elements of the model, for this to be successful.

The Gestural Mode

Parts of the body, typically including movements of the hands and arms, are used to visualize a model, most often almost unconsciously during direct interpersonal communication, e.g., when a teacher is talking to a class. Because it is invariably accompanied by speech, the preeminent mode of communication, the gestural mode of visualization is underappreciated in the lexicon of representation and hence has been under-researched. The gestural mode is of very great value to the hard of hearing.

The Symbolic Mode

The symbolic mode is the most abstract of all the modes of visualization, for in it both the entities constituting a model and their spatial relations and specific behaviors are reduced to single letters or groups of letters. The consequent reduction in demands made on a person’s memory capacity enables them to be readily manipulated relative to each of other, such that the imagination to be exercised.

There are two main symbolic modes used in science and hence in science education: the mathematical equation and the chemical equation. Both of them are attended by demanding codes of representation, and hence school students find them difficult to master. However, both are vital ingredients in the advanced study and practice of science, and so the attainment of mastery in both of them is a key indicator of success in pre-professional science education.

Multiple Representations

As discussed above, the various modes of visualization support to varying extents the representation of the several aspects of a given model. It has been found to be educationally valuable to use combinations of them when wishing to support the acquisition of effective and comprehensive learning of a given model. This is known as “multimedia learning” (Mayer 2002), for which three claims have been made. First, by presenting information in different modes, the likelihood of students understanding the core message through one of them is increased. Second, by presenting information in different modes, the likelihood of students being able to transfer it to different contexts is increased, for they do not associate the information with a particular mode. Third, by presenting information in different ways, the ability of students to actively construct knowledge is supported, this being a general goal of all education, including science education.

However, perhaps the main value of multiple representations lies in their use during progression through a course of study. Such a progression involves students acquiring an understanding of scientific explanations of greater depth. It has been found useful to represent this greater depth in terms of "levels of explanation."

Levels of Representation

The notion of a "level of representation" was first used in chemical education. Progression in the understanding of a chemical phenomenon is modelled (Gilbert and Treagust 2009) as moving from the macro level, to the sub-micro level, to the symbolic level, defined as:

- The macro level. Pure samples of a substance (an element, compound, or mixture) displaying the chosen chemical phenomenon in an exemplary way are prepared and the empirical properties that define it are assessed. The representation of these, say in the form of a table, together with the pure substance, constitute the macro level of understanding of it.
- The sub-micro level. A model is created of the entities on which the phenomenon is thought to rely (i.e., atoms, ions, molecules, free radicals). This model can include that of the bonding electrons within/between the entities, leading to conjectures about their shape. This model is then externally represented (e.g., in the material and /or the visual mode) and used to predict not only its existing properties but also those that should exist if the physical conditions were changed. The validity of these predictions is then tested empirically.
- The symbolic mode. At the symbolic level, the model of the sub-micro level is simplified. Thus, molar quantities of atoms are represented by signs (e.g., O), the use of superscripts used to show any electrical charges (e.g., O^{2-}) and suffixes used to show the physical state of species (e.g., $O_{(s)}$). The simplified representations of all the species involved in a reaction are then written as a chemical equation, such that matter is conserved, e.g.,

$$2Mg_{(S)} + O_{2(g)} \rightarrow 2Mg_{(s)}{}^{2+} + 2O_{(s)}{}^{2-}$$

This approach has been adopted for and extended for biological phenomena (Treagust and Tsui 2013), thus:

- The macro level. Here the larger-scale structures of a biological phenomenon are visible to the naked eye.
- The cellular level. Structures at this level are only visible under a light or electron microscope.
- The sub-microscopic level. Here the chemical species that constitute the cellular level are represented, e.g., DNA.
- The symbolic level. Here simplified versions of the sub-microscopic level are used in a quantitative way, e.g., to represent genotypes and metabolic pathways.

A similar treatment for phenomena that fall within the purview of physics is awaited.

Full explanations of phenomena of scientific interest thus involve all the levels of representation. These will use a wide range of modes of representation, implying that the successful scientist, and hence also the high-achieving science student, will need to understand and be able to use the codes of representation for every mode. Possessing this competence implies that a person not only has a detailed knowledge of all the modes and their codes but is able also to reflect on how that knowledge may be used and on the nature of the tasks to which it can be applied and to the ways in which this may be done. This capability may therefore be termed meta-representational competence.

The Demonstration of Meta-representational Competence

To demonstrate full meta-representational competence, a person:

- Should know and be able to confidently use the codes of representation for all the four major modes of visualization, being aware of the scope and limitations of the ways in which they represent entities and relationships in any given model. This primary requirement is made more complex because, in addition to generic descriptors of a mode, there are usually many sub-modes each with subtly different capacities, for example, "ball-and-stick," "space-filling," and "skeleton," versions of material models used for molecules in chemistry.
- Be able to use different visualizations in order to demonstrate the relationship between each of the levels of representation for a given phenomenon. For example, in respect to the function of the liver: to use a material model to show the position of the liver in the body, to use a different material model to show the cellular structures of the liver, to use yet a different material model to show the structure of the components of the liver, and to use a diagram to show the metabolic pathway by means of which the liver functions.
- Be able to "translate" the visualization facilitated by one mode into that made by another mode. For example, to show the relation between a material visualization of the composition of a crystalline chemical and that given by a two-dimensional diagram of it.
- Be able to construct a visualization within any one of the modes that is relevant to the requirements of the model. The "liver example" above would be such a case.
- Be able to use visualizations in order to solve problems that have not previously been encountered. For example, to represent the technique of hydrocarbon extraction known as "fracking" and to explore the possible consequences of it for geological stability in a given location.

Little if any effort is currently made to systematically develop meta-visual competence in either science students or their teachers. That both are needed is shown by research evidence that:

- Students are able to produce a visualization at the macro level but are unable to do so for the same phenomenon at the sub-micro or symbolic levels.
- Students find it difficult to "translate" the symbolic visualization for a phenomenon into the corresponding sub-micro one and vice versa.
- Students find it difficult to "translate" a given visualization between the sub-modes of a given mode.

The first step in making provision for such development must be to establish what is entailed and how it might be facilitated.

The Development of Meta-visual Competence

From a study of undergraduate chemists, Kozma and Russell (2005) identified five distinct stages – what they called levels – in the development of meta-visual competence. In summary, and adopting the word "phase" for them to avoid confusion over the meaning of the word "level," these are that in:

- Phase 1, students visualized a physical phenomenon solely as an iconic depiction of the original.
- Phase 2, students included some symbolic elements in such an iconic depiction.
- Phase 3, students included far more symbolic elements in their depiction, but these were often not scientifically accurate.
- Phase 4, students only used symbolic elements in producing a visualization and always did so correctly, being also able to transform a given visualization into one in another mode.
- Phase 5, students were able to use one or more appropriate and symbolically accurate visualizations to explain the relationship between the entities present in the phenomenon and the behavior they show, also being able to justify any such claims they make.

A student progressing from Phase 1 to Phase 5 will have undergone a major process of conceptual development both in terms of ontology and of epistemology. This development can be supported by teaching in which:

- Explicit use is made of several modes of visualization in discussing a given topic, relating their use systematically to the levels of representation used in that topic.
- The introduction of those visualizations starts from the one that is both the simplest and the most iconic and progresses to the one that is the most comprehensive and most symbolic, explaining the appropriate codes of visualization as the sequence is followed.
- The differences between the visualizations is emphasized by the use of sharp edges, distinct shapes, shading, and color.
- Use is made of stereodiagrams to enhance students capacity to understand the 3D nature of a model (if that is relevant) from a 2D visualization of it.
- The skills of reflection and rotation are systematically exploited.

Indeed, these and other strategies should also be included in teacher development programs.

Teacher Development for Meta-visual Competence

The general principles of good practice for teacher education programs, whether preservice or in-service (Gilbert 2010), certainly apply in designing and providing professional development activities on the theme of visualization. These activities could readily serve two functions: the development of the teachers' own capability and the demonstration of how these themes can be incorporated into schemes of work for students. The activities should thus:

- Be philosophically and practically congruent with the intended purpose. This criterion can be met in three ways. First, have the teachers develop visualizations for use in their own teaching. Second, have them analyze the design and intended use of the many visualizations that are included in the textbooks issued to students. Third, have them explore the teaching potential of the many computer software packages for the generation of visualizations that are available.
- Recognize that learning, including that of teachers, is a social activity. An organization of activities such that they lead to an atmosphere of "critical support" among participants working in small groups will enable them to see both that they share many of the same challenges and that they can cooperatively arrive at solutions to them.
- Enable activities to be spaced such that reflection on what has been learned can occur. One way of doing this is to have participants develop visualizations that are to be used with classes before the next teacher education meeting, to evaluate their implementation, and to report back at that meeting.
- Monitor the consequences of the professional development activities for the evolution of classroom practice. This can be expensive in terms of expert counselling but the impact is likely to be substantial.
- Require participants to engage in action research. The process of developing meta-visual capability is likely to be a lengthy one such that the taking of small steps and evaluating their significance is the soundest way forward.

In the course of such activities, myriad small changes should be sought to overcome what is known about shortcomings in teachers' knowledge and skills. Thus teachers should be encouraged to:

- Adopt the correct terminology for the field.
- Use appropriate modes of visualization, not only the iconic form.
- Use visualizations throughout a topic and not just during its introduction.
- Explain when changing the mode of visualization being used why this is being done.
- Only use personally developed visualizations when they have been prepared and considered before their use in a class.
- Develop their pedagogic content knowledge about the use of visualization in general.

The Assessment of Visual Capability

There is clearly a need for instruments that, severally or collectively, assess students' progress on the road to meta-visual competence. Although many partial instruments have been produced for more narrowly conceived research purposes, typically concerned with the skills of "rotation" and "reflection," it will only be when the development of meta-visual capability is placed as a central commitment of science education that comprehensive, teacher-friendly, packages will be developed.

Cross-References

- ▶ Models
- ▶ Multimodal Representations and Science Learning
- ▶ Representations in Science
- ▶ Scientific Visualizations

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Web 2.0 Resources for Science Education

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Keywords

Blogs; Search engines; User-generated content

The Internet has increasingly become the main source for science-related information for Western societies (National Science Board 2014). Web 2.0 was coined to describe the second generation of the World Wide Web that shifted from passively viewing content from static web pages to a focus on users' ability to interact, collaborate, generate, and share information online. Web 2.0 includes wikis (e.g., Wikipedia), blogs (e.g., ScienceBlogs), podcasts (e.g., RadioLab), video sharing (e.g., Khan Academy on YouTube), massive open online courses (e.g., Coursera), social networking sites (e.g., Facebook), and many other applications. Web 2.0 digital and interactive technologies have enabled nontechnical citizens to become consumers as well as producers of science content by creating, changing, linking, remixing, and disseminating information on a global scale at relatively low cost.

Web 2.0 provides opportunities for eliciting public engagement with science in informal environments and students' engagement with science within formal K–12 and higher education environments, as well as unique affordances for educational research.

Although the traditional digital divide between people with and without access to the Internet has declined, a second-level digital divide has emerged involving what people do with the Internet, and it is becoming wider. This divide may relate to actual and perceived web skills and is correlated with demographics such as gender, educational background, and age. "Digital natives," for example, the generation born after 1982, have been immersed in an environment of digital technologies for their entire lives and are said on average to have better understanding of its value and application to their lives. The daily interactions of digital native students increasingly involve information and communication technologies (ICT), but their in-school learning have been found to be technologically impoverished or use controlling technologies to restrict Internet use. These students are increasingly turning to the Internet to complete educational assignments, regardless of whether the assignments are intended to involve Internet use.

The evaluation of information sources is a critical subskill for any complex task that involves learning from multiple digital sources. Web users must critically evaluate diverse and sometimes contradictory sources of information. This situation shifts the burden of information evaluation to the reader, since web-based

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information may lack reliability due to the absence of a professional gatekeeper (e.g., editor). However, research has shown that users do not usually make the effort to appropriately evaluate the quality of information obtained on the web and the quality of its source. Luckily, evaluation skills are amenable to improvement through instruction. Beyond their contribution to the effectiveness of inquiry learning in science, these skills may be even more important for successful lifelong learning and making real-world decisions (Wiley et al. 2009).

One of the hallmarks of Web 2.0 is the introduction of new capacities for information seeking, sharing, and aggregating. Research on science students' information seeking has involved assigned tasks, like using digital libraries, or plagiarism prevention, rather than self-generated search tasks. However, new data mining and analysis tools can now document trends in science-related web searches. In 2006, Google launched Google Trends. This public web tool tabulates how often a particular search term has been entered into the Google search engine versus the total search volume across time periods, various regions, and languages. Data on online searches, which reflect a conscious effort to acquire information, have been used to study trends in health, economics, and science information seeking. Studies measuring public interests in science have found that searches for general and well-established science terms were strongly linked to the academic calendar, meaning that the trigger for the search was probably the education system.

On the other hand, searches for concepts related to ad hoc events (e.g., Nobel Prize announcements) and current concerns were better aligned with media coverage. Web searches on nanotechnology indicated that the public was mostly interested in future directions but was less interested in policy and regulation. However, significant differences in search behavior have been found depending on the wording of the search query. Studies demonstrated cases of discrepancies between the science topic people search for online, specific areas suggested to them by a personalized search engines and what people ultimately find. This is important, since search results may shape users' perceptions, knowledge, and discourse about emerging technologies (Brossard and Scheufele 2013).

Ask-A-Scientist sites are aimed at providing students and the general public direct access to legitimate scientific knowledge in an accessible manner. One project called Madsci, for example, enables a direct exchange between scientists and students. Analysis of usage demonstrates a surprising dominance of female contributions among K–12 students, whereas offline situations are commonly characterized by a greater interest in science among males. This female enthusiasm was observed in different countries and had no correlation to the level of equality in those countries. This may indicate that the Internet as a free-choice science-learning environment plays a potentially empowering and democratic role. However, an analysis of 10 years' worth of data revealed that girls' interest in submitting questions to scientists dropped all over the world as they grew older, and the stereotypically gendered science interests persist in this environment as well (Baram-Tsabari et al. 2009).

Social networks have increasingly become a channel for distributing and publicly debating scientific information. The microblogging social network Twitter has been used in schools to provide instant feedback tool during class, as a means of triggering in-class discussion and a technology-based strategy to support informal learning beyond the classroom. Educational use of social networking sites may involve the replacement of common online learning management systems (e.g., Moodle) by private Facebook groups specifically created for classroom communication. Examples include enhancing students' participation in an introductory chemistry laboratory course or knowledge sharing in a history course where students uploaded profiles of relevant historical figures.

Reader comments to online news articles is another way in which Web 2.0 capabilities have begun to transform web activity from being passive to being more active, through creating content in the virtual world. This is a great opportunity for public engagement with science, where citizens can now add their voices to published content, as well as repost, up-vote, or use various other means of adding social information to the original content. In recent years, reader comments about science online media coverage have been used to learn about the concerns, sources of information, and knowledge of participants in discussions about socio-scientific issues, such as animal experimentation, nanotechnology and climate change. It was found that the most fruitful discussions within comments were initiated in the discussion threads themselves, rather than in the science news articles, indicating that the audience participation now plays a role as a "growth medium" in which seeds flourish through reader contributions. On the other hand, the effects of online incivility in reader comments have been found to effect the perception of risk toward science-related issues.

The changing nature of the web as well as the changing nature of "classrooms" where learning can take place across physical and cyber spaces in and out of school provides twenty-first-century learners with an array of choices for the topic and location of their learning experiences.

Cross-References

- ▶ E-Learning
- ▶ ICT in Play-Based Contexts
- ▶ Internet Resources: Designing and Critiquing Materials for Scientific Inquiry
- ▶ Lifelong Learning
- ▶ Technology for Informal and Out-of-School Learning of Science
- ▶ Wikis

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Wikis

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Background

A wiki is a collaborative website that allows users to add, delete, and edit content via the Web browser on a networked computer. What distinguishes wikis from other programs, such as word processing software, is that the documents remain available for ongoing editing by those who have membership to the wiki. Wiki membership can be of any size – from small groups and classrooms, to schools, communities, and the entire world. Wikipedia, the well-known online encyclopedia, popularized both wiki technology and the idea of collaborative writing. Wikis are primarily used for the co-construction of text-based documents, which are referred to as wiki pages. Wikis can also include other types of media; even the most basic and freely available wiki software enables users to embed videos, links, and images within the wiki. Certain commercial wikis, such as those used in business and industry, have increased functionality including group calendars, advanced search capabilities, and content streaming.

Wikis are suited for all levels of education, including formal K-12 classrooms, higher education, and informal learning settings. They serve many educational purposes. Teachers have used them as a platform for content management, a repository for class projects, and as a forum for group discussion. Wikis are easy to learn and require little or no training to be used productively, a factor that has contributed to their widespread usage among educators. Wikis support the ongoing reflection and refinement of ideas by maintaining an archive of students' contributions and edits. The publication of student work, even when limited to their peers, legitimizes their contributions within the wider class community. The co-writing of wiki pages can also lead to important transferable skills, including problem solving, communication, decision-making, and teamwork.

Wikis in Science Education

Wikis can be a valuable tool for creating knowledge resources for science education. When editing content, students make decisions about the ideas and information that have been contributed by their peers. In doing so, they may engage in negotiation and consensus making, processes that are important for learning and foundational to theories of social constructivism. The collaborative component of wikis makes it possible for all students to contribute their ideas and perspectives. The growing collection of resources that students co-create and share comes to represent the collective knowledge of the class. For this reason, wikis are suitable for knowledge communities, where students rely on the knowledge and contributions of their peers for their science learning. In addition, the ability to include hyperlinks, either to external websites or to links within the parent wiki, can support students in making connections between the ideas and information that are contained within the wiki pages.

One of the challenges of using wikis for science education involves the measurement and assessment of student contributions. Wikis include detailed history logs that keep track of the moment-to-moment edits made to wiki pages. These history logs are typically voluminous and complex and are difficult to use and make sense of without extensive analyses. Educational researchers have developed both sophisticated technological tools and simple metrics for assessing the quality of students' wiki contributions, as well as measurements of their collaborative efforts. The challenge of developing valid and reliable assessment instruments is ongoing, including efforts to develop practical tools for K-12 science teachers that can be used for assessing student performance.

Wikis are used in both formal and informal science learning environments. The Informal Science Education Evidence Wiki provides summaries of research on informal Science, Technology, Engineering, and Math (STEM) education and provides a forum for public discussion about informal science learning. Wikispaces has been used extensively by science educators at all levels and is popular for providing a free and accessible wiki space that includes teacher-controlled permissions for content and file viewing. Regardless of the educational context, wikis can contribute to science leaning in a number of important ways. Collaborative wiki writing supports scientific literacy, the acquisition of disciplinary content, and the development of twenty-first century skills. Wikis are also a valuable educational resource for helping learners of all ages to become informed consumers and producers of science.

Cross-References

- ▶ Collaborative Learning in Science
- ▶ Computers as Learning Partners: Knowledge Integration
- ▶ Constructivism
- ▶ Digital Resources for Science Education
- ▶ Internet Resources: Designing and Critiquing Materials for Scientific Inquiry
- ▶ Knowledge-Building Communities
- ▶ Science and Technology
- ▶ Science, Technology, Engineering, and Maths (STEM)

Worldview

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Worldview provides a nonrational foundation for thought, emotion, and behavior. Worldview provides a person with presuppositions about what the world is really like and what constitutes valid and important knowledge about the world. It is, according to Kearney, "culturally organized macrothought: those dynamically inter-related basic assumptions [i.e., presuppositions] of a people that determine much of their behavior and decision making, as well as organizing much of their body of symbolic creations. . . and ethnophilosophy" (1984, p. 1). Worldview is thus about metaphysical levels *antecedent* to specific views that a person holds about natural phenomena, whether one calls those views commonsense theories, alternative frameworks, misconceptions, or valid science. A worldview is dynamic colocation of mostly implicit fundamental presuppositions on which these conceptions of reality are grounded. Because worldview is an exhaustive concept that far exceeds the realm of science for all but the most extreme scientistic believers, it is problematic to speak of a *scientific* worldview. Scientific ideas can be grounded in many worldview variations. Scientists have come to their work from very different worldviews. There is not one worldview that is required for scientific thinking or for valuing science. A scientifically *compatible* worldview is thus a more accurate and useful construction for the vast majority of persons. This construction puts emphasis on the integration of scientific thinking with other powerful ways of thinking that are important to people. It guards against the twin problems of scientistic and antiscientific thinking.

Cross-References

- ▶ Cultural Influences on Science Education
- ▶ Rika

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Writing and Science Learning

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Keywords

Criteria for writing; Knowledge bases; Writing-to-learn

Writing has been used in every classroom in every country since the time schooling began. Students have been asked to copy notes from the board, record their experiments, and complete assignments for eons. The major role of all of this writing was for the students to have a record of what was being said and what they understood. The function of writing was to produce a product – there was only a limited focus on the process. It was not until the mid-1970s that the idea that writing was both a process and a product began to emerge. The idea that writing was more than just a record of work or talk written down, something that could help students learn, focused research on understanding how this was possible.

The shift in thinking about writing occurred around the time that there was beginning to be a shift in how science was taught. Much of what had been the focus of the 1960s and 1970s in science was based on behavioral learning, that is, students were provided with information and skills that they were required to give back or perform. There was the added restriction in some countries that curriculum and students' progress were based on the stages of development theory derived from Piaget, with the central premise that students were unable to advance their cognitive work until they had reached particular ages. The focus of science teaching was much more on the product, not the process.

Process and Product

If writing is not simply a product but a process, then the question becomes as follows: What is the process? What is actually happening during the process of the construction of the text? Is the process a series of steps, that is, a set of behaviors? Can the process of writing be simply a matter of mastering a series of steps? Or is it a cognitive process? That is, is the process of writing something that is internal to every individual? These two different perspectives have led to an ongoing debate between contrasting positions – the "learn-to-write" position and the "writing-to-learn" position.

The initial research on writing occurred during the 1980s. This involved a great deal of focus on establishing the steps that were required to complete a writing task. If writing is more than talk written down, how is the process of writing achieved? In understanding that the end goal of writing is a product – a completed piece of writing – how does an individual plan and complete the process? Do they have a series of steps to complete? This was the focus of much of the work in the 1980s. Research was done that was centered around understanding what the necessary steps an individual had to complete were. This resulted in a focus on the issues related to genres or particular types of writing, what the structures of the genres are that a writer has to put in place for success, and what the writer has to know to be successful in terms of being able to write in different genres (persuasive writing, narrative writing, expository writing, argumentative writing, information writing, etc.).

This led to the work of Halliday and Martin (1993) whose book has very much guided the "learn-to-write" movement in science education. For these researchers, there was a very strong push to have students learn the structure of the genres before doing science. For example, they believed that for students to learn from science, they had to know the structure of the laboratory report before they could use it for inquiry activities in the classroom. Many researchers have adopted this important position, that is, you first have to teach the structure of the genre (e.g., laboratory report) before the students can use it. For students to have success in the laboratory, they have to be able to complete the traditional format of hypothesis, data, results, and conclusions.

This position is still the focus of what happens in many science classrooms today. That is, the value of writing is framed around having the correct structure and ensuring that this structure is completed. However, this raises questions such as the following: What does it mean to learn using this approach? How does completing a genre actually produce successful learning? Is the learning achieved in the actual writing or in completing the structure? For example, is writing the laboratory report itself where the learning occurs, that is, making sure that the hypothesis is connected to the data, to the results, and to the conclusion, the crucial component of the learning? Or is the learning gained in filling in each of these sections?

Many teachers of science spend the first week or so of each year making sure that the students know the "scientific method" and know how to write up their laboratory reports. It is believed that ensuring that this structure is firmly in place will enable students to learn science better – the position of the learn-to-write movement. The results of many studies have shown that there are roughly an equal number of positive gains as negative consequences using this particular orientation.

Shifting the Focus

In trying to explain how learning does occur through writing, Bereiter and Scardamalia (1987) put forward a model that highlighted that there are in fact two knowledge bases that need to be engaged with in writing – the rhetorical knowledge base and the content knowledge base. In terms of rhetorical knowledge, each author has to know what the requirements of the structure of the genre (complete sentences, paragraphs, etc.) as well as the purpose of the genre (to inform, informational essay; to persuade, argumentative report; etc.). The content knowledge base encompasses what needs to be actually described using the rhetorical knowledge base. That is, if a student is asked to write about force and motion, then he/she has to make decisions about the particular aspects of force and motion he/she is going to use – straight line motion, speed, velocity, acceleration, etc.

Bereiter and Scardamalia argued that each author will only be able to operate one knowledge base at a time – they are either using the rhetorical knowledge base and then moving to the content knowledge base or vice versa. There is a constant movement back and forth between these two knowledge bases.

Bereiter and Scardamalia highlighted two critical caveats with their model. The first was that there would be constant motion back and forth between these knowledge bases until the task was finished. Each individual would be using one knowledge base, for example, the rhetorical knowledge base, before moving to the other knowledge base in completing the writing task. The second is that there are two different outcomes of the writing process – knowledge telling and knowledge transformation. They believe that there are two major functions involved as the outcome of the writing process. Knowledge telling is where the emphasis is on recall of information – recalling what information you have stored and telling the reader what it is that you know. There is acknowledgement that there is no change to the knowledge the writer is describing.

In one sense this form of writing can be considered as a memory dump. The knowledge transformation process however is very different to the knowledge-telling process. In this process what the individual knows is changed or transformed by the actual process of writing about it. It is through the writing process itself that the knowledge is transformed. This was an important breakthrough in terms of understanding the value of writing – knowledge is not transformed before writing it down; it is transformed through the writing process. As the individual completes a writing task that goes beyond simply telling, then they are going through a process where what they know is being transformed by engaging in the process of writing itself.

This critical breakthrough was important in framing an argument that moved writing away from a procedural view of a planning and production process to engaging more with the idea that writing was in fact an epistemological tool. Through the process of writing, an individual can come to know more about the topic than they did before they started. That is, writing is much more than a process of thinking about what to write, shaping the sentence, and then writing the sentence. Writing became a process that in the moment of writing, there is thinking and that as a result of the writing, more thinking occurs. As one puts pen to paper (or now we would say, fingers to the keyboard), the outcome of the previous text will generate different thinking to that that was occurring before the text was constructed. If you think about any example where as you were writing you became excited because suddenly there were new ideas flowing from your "pen," then you have a very stark example of this process. A situation in which you are going in one direction and suddenly as you are writing, there are many new ideas emerging as if from nowhere is a very clear example of writing as an epistemological tool.

Improving Our Understanding of the Process

As with any theory put forward to explain a phenomenon, there is always some disagreement which then leads to advancement of ideas. This was the case in the writing research community. A model put forward by Galbraith (1999) helped generate a richer understanding of the writing process. One of the disagreements with the previous model put forward by Bereiter and Scardamalia was around the idea that the knowledge transformation process did not build new knowledge but rather only transformed what already existed – the process, Galbraith argued, did not in fact lead to knowledge that was new and different to that which previously existed.

Galbraith agreed with the idea that there are two different knowledge bases that need to be engaged with when writing, but he argued that there was a dialectic or dialogue between these that is continuous and not dependent upon being in one or the other knowledge base. His argument was that it is through this dialectic, this continuous interaction, that text gets built. Importantly, the dialectic produces new and different links with the knowledge that currently exists, so that it is in fact constituted in a different way, resulting in new knowledge. The links between points within the web of stored knowledge are generated in new ways, and hence, what is constructed is different to that which previously existed. This newly constituted knowledge allows the individual to come to know the topic/idea in a different way than before. That is, writing is an epistemological tool.

This was a really critical shift for researchers because this meant that the idea of writing was not just to demonstrate what an individual knows but rather to see each writing task as a learning task. All the writing tasks that students engage with, apart from straight note-taking which is nothing more than copying exactly what is written down somewhere else (notes from the board, copying a summary from a textbook, etc.), become learning tasks. The view of researchers of writing tasks shifted from being about the production of some finite product to understanding that the process of production in itself is part of the learning process. This means that not only are the assigned writing tasks within a topic learning tasks, but when extended response questions are used on a test, these become writing-to-learn tasks as well. That is, even while they are completing a writing task as part of an examination, individuals are going through a learning process.

Shifting from “Fuzziness”

The final piece of theory that has been guiding the writing-to-learn movement in trying to understand how writing is an epistemological tool is the work of Klein (1999). In explaining how writing is a learning process, he posited that there are a number of different positions. These ranged from the concept of genre, that is, learners have to understand the structure of the writing task (genre) to be able to use it as described above, to what he termed “backward and forward searching.”

Backward searching resembles the planning phase described in the early studies of writing in that he argued that learners have a plan for completing the task. By continually referring back to the plan as he/she moves through each part of the plan, the learner is able to complete the task. However, the point of construction of the text is where the learner will search forward to continue to complete the writing of the sentence, paragraph, and/or whole text. It is this interaction between completing the plan (backward searching) and continually having to go forward in the construction of the text (forward searching) where learning occurs. The planning process does not imply there is planned text prior to writing but rather there is a plan in what needs to be completed.

The goal of this interactive process of backward and forward searching is to move from fuzzy understanding to an understanding of the canonical forms of science knowledge. For Klein it is this second-generation cognitive psychology position of fuzziness that is the driver of the epistemological gains made through writing.

As a learner writes, they will shift from being fuzzy about the idea toward the first-generation cognitive psychology position of canonical knowledge, that is, toward what is the recognizable science knowledge. This in essence is what is meant by writing as an epistemological tool – through writing the learner is able to shift from being fuzzy about the concepts being studied to a place where they know or understand the ideas being studied.

Conditions for Using Writing

As the view of writing shifted from production to process to understanding that writing is an epistemological tool, then there was a push to determine what the critical criteria were in helping to maximize the learning outcomes. There has been much work done on framing some critical elements that learners need to be aware of or are required to engage with in using writing as a learning tool. These elements include audience, writing type, topic, purpose, and method of production. These are discussed below:

Audience – learners constantly have to write to the teacher as the audience for their writing. The problem with this is that they are playing the game of giving the teacher back what he or she wants to see. This can include bold words from the text or the words highlighted by the teacher as well as ensuring the complex explanation used in the textbook is part of the written product. The trouble with this is that instead of being placed in a position of explaining the ideas, the learner merely repeats what has previously been given to them. By choosing an audience other than the teacher, the demands on the learner shift, particularly when the audience is their peers or a younger group. Students need to be placed in a position where they are forced to break down the "big" scientific words in order for the audience to understand what they are trying to explain. By asking learners to write to a real audience who will participate in scoring their work, the learner is placed in a position to have to explain the science words to himself/herself as well as the audience, hence encouraging a much richer engagement with the topic.

Writing type – traditionally, learners are required to write using a small number of different writing types within the science classroom. These include laboratory reports, chapter summaries, notes from the board, and an occasional creative essay about, say, a day in the life of a red blood cell. When instead learners are asked to write using nontraditional writing types such as letters to the editor, travel brochures, creative stories, etc., they have to deal with issues that focus on both the rhetorical demands of the writing type and the need to correctly explain the science concepts. These different types are not about fictional science, but about having to explain to others the scientifically correct concepts in ways that require the learner to break these ideas down and consider them in contexts other than the science classroom.

Topic – commonly, science is taught via the teacher breaking the ideas down and laying out a linear path to understanding, with the Internet that every learner will be able to put the pieces together correctly. Very rarely are learners provided with the "big idea[s]" of the topic – somehow it seems it is supposed to be obvious to everyone. However, there is a need to use writing tasks that are centered on asking students to focus on the conceptual frame of the topic. It is through having to explain the "big idea [s]" of the topic that the students will attach meaning to all the content of that idea. Thus, writing tasks should focus on what is the framing concept of the topic under study.

Purpose – there are many purposes for using writing within the science classroom. These include the following: at the start of the topic in order to determine what students know, in the middle of the topic to provide opportunities for learners to gather their thoughts together, or at the end of the topic to demonstrate what they have constructed as the conceptual frame of the topic. Building on the idea that each writing activity is a learning opportunity, the purpose of the learning itself can shift depending on the timing of the writing opportunity.

Method of text production – given the changes in the use of technology in schools, then the construction of the written text can shift from the more traditional pen to paper to any of a range of electronic platforms. This shift also has consequences for how a learner constructs the text they write because the ease in which they can change text, shift text, or cut out text is a very different writing process than the traditional method of construction. The method of text production also refers to the idea that a text can be constructed in other ways apart from an individual endeavor. For example, is the construction a group effort? Or do individuals contribute to part of a text? These are decisions that have to be taken into consideration when framing a writing task.

The above elements can be used to frame different writing tasks for any learning situation. The particular combination of these elements is determined by the context of the situation and the learners that are to undertake the task. However, results to date indicate that much benefit is gained in using these critical elements to help in constructing the writing tasks.

Students' Understanding of Writing

In a secondary reanalysis of a series of qualitative studies over a 10-year period, McDermott and Hand (2010) showed that students are very aware of the benefits of using these writing-to-learn approaches within classrooms. That reanalysis highlighted that students identified three characteristics of the writing task that were beneficial – writing to a different audience, the opportunity to do multiple drafts, and the opportunity to receive real feedback. Importantly, students were aware that while these writing tasks are time-consuming and difficult, they were getting learning benefit from completing the tasks, particularly because these tasks required them to think more about the topic. They were very aware that having to deconstruct science terms for their audience was beneficial for their learning. Having to break down such ideas as "photosynthesis" into its component parts for younger students means that the author really has to understand what these component parts are, rather than simply feeding back to the teacher the term itself.

In another secondary analysis, Gunel et al. (2007) were able to show that there are statistically significant performance advantages for students on tests when they are involved in writing approaches in the science classrooms. The analysis also showed that students' test performance was significantly boosted when they were required to answer conceptual questions or extended response questions.

Importantly, these results showed that not only do writing-to-learn approaches improve students' understanding of content/concepts, it also enhances students' understanding of why and how there was benefit for them. By using such approaches, we can generate a greater involvement for students and hence increase their chances for success.

Future Directions

Currently, there are a number of different directions being taken by research on writing-to-learn approaches. These include two very promising areas of work. The first is on science argumentation while the second is centered on multimodal representation. Both of these research ideas extend writing-to-learn approaches beyond what has been seen as the more traditional ideas of writing.

Science argumentation is now being recognized as a central practice of science. It is how science knowledge is advanced. As such this raises critical questions about how we can use writing as a critical learning tool in the building of students' knowledge of argument and science at the same time. This shifts the focus from using writing-to-learn approaches for engaging with already defined ideas to working with students to use writing as a learning tool in understanding how science knowledge is constructed. How can we use writing as a means to help students learn about questions, claims, and evidence and the relationship between these as a means to building understanding of the science itself? Given the shift in some recently released national science curricula to a great deal of emphasis being placed on the argumentative practices of science as central to the advancement of science, such questions become critical.

The second area of focus is broadening the use of writing to focus on how to embed multimodal representations as a critical part of the language. This focus places emphasis on broadening the idea of language to move beyond just writing. Given the shift in how technology is being used in classrooms, we need to explore how writing and other modes of representation can help students learn science. Writing is the "glue" that helps students move between representational modes, but as yet we have not explored the best ways to incorporate all these modes, how students engage with the modes, and the best ways to represent science ideas from the student perspective in terms of different writing opportunities. This research holds much potential for advancing how we can help all students learn.

Cross-References

▶ Argumentation
▶ Discourse in Science Learning
▶ Language and Learning Science
▶ Metacognition and Science Learning
▶ Reading and Science Learning
▶ Representations in Science

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Z

Zone of Proximal Development

► Socio-Cultural Perspectives on Learning Science

Zoological Gardens

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Keywords

Wildlife centers; Zoological parks; Zoos

Zoos are collections of animals displayed in designed settings, typically open to the public. The earliest zoos were private menageries designed to demonstrate the wealth and influence of royalty. Some served as “libraries” of living things of great educational value to the scholarly elite, though many were merely meant for the amusement of those permitted access. Over time, the mission of modern zoological parks has evolved to a current focus on conservation, education, scientific research, and recreation. The emphasis on the conservation and educational mission of zoos in particular has led to a change in the way the zoo experience is presented to guests. Modern zoos take very seriously their role as conservation centers that inspire guests to take an active role in protecting wildlife and wild habitats (Myers et al. 2004).

Historically, learning at the zoo primarily meant transfer of knowledge from expert to guest, by acquisition of facts and figures about the animals on exhibit. More recently, zoo educators have begun focusing on how the learner experiences the zoo and its educational programming in an effort to ensure that the zoo experience has a positive impact on learners’ attitudes and behaviors related to wildlife conservation (Myers et al. 2004).

The World Association of Zoos and Aquariums reports that global zoo and aquarium attendance tops 700 million visitors annually. Because of their ubiquity and popularity, zoos can claim to be key settings designed to support science learning by people across the life span. Research has shown that the general public value zoos as places where children develop and strengthen connections to nature and where families make discoveries and learn about science together (Fraser and Sickler 2008). Zoo experiences are uniquely positioned to inspire guests to become interested in science, to ask questions about what they observe, and to reflect on the world around them and how they can learn more about it. Zoo educational programming often encourages guests to become active participants in science learning and, in so doing, inspires guests to view themselves as life-long science learners.

Subject matter that visitors encounter through their zoo experiences include conservation, animal behavior, animal husbandry, environmental

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science, research methods and equipment, analytic tools of mathematics and engineering, natural and engineered habitats, veterinary science, ecology, and more. The types of engagement that are encouraged in visitors include appreciation, respect, empathy, awareness, conserving, activism, and stewardship. The educational programs offered range from guided tours to classes, camps and clubs, remote field trips and web-based courses, internship opportunities, conferences and workshops, citizen science projects, outreach visits, and travel, among other programs. Audiences are varied; many zoos offer specialized programming from early childhood through adulthood.

Efforts to refine the educational focus of zoos and the work of their staff have been developing in earnest over the past 20+ years. Collaborations with conservation groups and universities have multiplied; educational experiments have been funded; best practices are being identified and shared; increasing numbers of zoological facilities are investing significantly in evaluation efforts; research on the educational impact of zoos is building on what have been identified as critical features of learning in other informal science settings. The nature of working with living collections, however, makes the setting unique and research on zoo-based education will take its own direction as more studies are undertaken.

The issues attendant with measuring outcomes in other informal settings apply to zoos as well, but recent research points to the effectiveness of zoos (and aquaria) for learning and engagement (Fraser and Sickler 2008). For example, research has shown that interactivity by and with animals encourages caring (Myers et al. 2004). Introducing mathematics activities in zoo programming allows zoo staff to engage visitors in some of the work of animal scientists and demonstrated to teachers that zoos are an ideal setting for introducing and reinforcing students' math skills. Ongoing studies are examining the impact of a zoo visit on guests, using a variety of indicators (Dierking et al. 2002).

Many zoo guests may simply seek an outdoor stroll with family and a chance to observe interesting creatures. Zoo professionals see opportunities to help visitors stop and notice, reflect and wonder, and become aware of their connections with nature and of the work of zoos themselves. The ultimate goal of zoo-based education is to inspire guests to develop attitudes and behaviors that support wildlife and habitat conservation.

Cross-References

- ▶ Aquaria
- ▶ Botanic Gardens
- ▶ Citizen Science
- ▶ Interpretive Centers
- ▶ Learning Science in Informal Contexts

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