Science Standard-Specific Supports

Chemistry

Revised October 2022

Contents

Science Standard-Specific Supports

Overview

The West Virginia College- and Career-Readiness Standards for Science[1] identify what students should know and be able to do at the end of science instruction. Each standard represents the integration of three "dimensions" of science education: practices of scientists and engineers, core science content, and science connecting concepts. As such, both student learning and assessment around the standards should be "three dimensional." The Science Standard-Specific Supports in this document are intended to show what it looks like for students to fully satisfy the intent of the standard.

The Science Standard-Specific Supports are adapted from the Evidence Statements of the Next Generation Science Standards (NGSS)[2], created when West Virginia was a lead state during the NGSS writing process, and the Framework for K-12 Science Instruction[3], created prior to the development of the NGSS. For more information on the Evidence Statements, please refer to them in their original form.

Purpose

The Science Standard-Specific Supports were designed to articulate how students can use the practices of scientists and engineers to demonstrate their understanding of the core science content through the lens of the science connecting concepts, and thus, demonstrate proficiency on each standard. The Science Standard-Specific Supports do this by clarifying:

- how the three dimensions could be assessed together, rather than in independent units;
- the underlying knowledge required for each core science content;
- the detailed approaches to the practices of scientists and engineers; and
- how science connecting concepts might be used to deepen content- and practice-driven learning.

The Science Standard-Specific Supports are not intended to be used as curriculum or limit or dictate instruction.

Structure

The practices of scientists and engineers are used as the organizing structure for the Science Standard-Specific Supports. However, this does not mean that the practices are more important than the other dimensions. The practices of scientists and engineers form the activities through which students demonstrate understanding of the science content. The proper integration of the practices makes students' thinking visible.

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[1] *West Virginia College- and Career-Readiness Standards for Science* (Policy 2520.3C) https://apps.sos.wv.gov/adlaw/csr/readfile.aspx?DocId=54673&Format=PDF

[2] NGSS Lead States. 2013. *Next Generation Science Standards: For States, By States.* Washington, DC: The National Academies Press.

[3] National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Washington, DC: The National Academies Press.

How to Use the Science Standard-Specific Supports

- For instruction:
  - The Science Standard-Specific Supports can be used to aid instructional design, but it is crucial to recognize there are numerous pathways educators may use throughout the sequence of lessons and units to allow students to ultimately be prepared to demonstrate mastery of the standards.
- For assessment:
  - The Science Standard-Specific Supports can be used to inform the development of formative and summative assessments by the classroom educator.

Although supports are listed individually for each standard, this does not indicate that they should be measured individually, or that standards should be taught or assessed individually. Best practices in classroom instruction should be focused on helping students build towards several standards at one time because many concepts and practices are interrelated.

Limitations of the Science Standard-Specific Supports

The science standard supports cannot do the following:

- Provide or prescribe the contexts through which the standards may be taught or assessed.
- Be the rubrics on which levels of student success would be measured.
- Identify the sequence of instruction or assessment.
- Put limits on student learning or student coursework.
- Replace lesson plans or assessment items.
- Serve as complete scoring rubrics.

*Only the standards for which specific Science Standard-Specific Supports exist are included in this document. Please refer to the complete standards policy (*West Virginia College- and Career-Readiness Standards for Science* (Policy 2520.3C)) when planning instruction.

Chemistry Introduction

Chemistry is an advanced elective course designed for students pursuing Science Technology Engineering Mathematics (STEM) education and careers. Students will develop a deeper understanding of the central concepts of Structure and Properties of Matter, Chemical Reactions, and Applications of Chemical Reactions as they prepare for college chemistry requiring a strong mathematical foundation. The chemistry course prepares high school students to explain more in-depth phenomena central not only to the physical sciences, but to life and earth and space sciences as well. The chemistry standards blend the central ideas with the practices of scientists and engineers and science connecting concepts to support students in developing useable knowledge to explain ideas across the science disciplines. There is a focus on multiple indicators, including developing and using models, planning and conducting investigations, analyzing and interpreting data, using mathematical and computational thinking, and constructing explanations. Students will use these practices to demonstrate understanding of the central ideas and demonstrate understanding of several engineering practices, including design and evaluation. Students will engage in active inquiries, investigations, and hands-on activities at least 50% of the instructional time as they develop and demonstrate conceptual understandings along with research and laboratory skills described in the standards and indicators for science. Safety instruction is integrated into all activities, and students will implement safe procedures and practices when manipulating equipment, materials, organisms, and models. Standards followed by an asterisk (*) denote the integration of traditional science content with an engineering practice.

College- and Career-Readiness Indicators for Science Grades 9-12

<table>
<tr><th colspan="2">Nature of Science</th></tr>
<tr><td colspan="2">• Scientific knowledge is simultaneously reliable and subject to change based on empirical evidence and interpretation.
• Scientific knowledge is obtained through a combination of observations of the natural world and inferences based on those observations.
• Science is a creative human endeavor which is influenced by social and cultural biases.
• A primary goal of science is the formation of theories and laws. Theories are inferred explanations of some aspect of the natural world based on successfully tested information from evidence and evaluated phenomena. Laws describe relationships among what has been observed in the natural world.
• Scientific investigations use a variety of methods to address questions about the natural and material world.</td></tr>
<tr><th>Practices of Scientists and Engineers</th><th>Science Connecting Concepts</th></tr>
<tr><td>• Asking questions and defining problems
• Developing and using models
• Planning and carrying out investigations
• Analyzing and interpreting data
• Using mathematical and computational thinking
• Constructing explanations and designing solutions
• Engaging in argument from evidence
• Obtaining, evaluating, and communicating information</td><td>• Observing patterns
• Investigating and explaining cause and effect
• Recognizing scale, proportion, and quantity
• Defining systems and system models
• Tracking energy and matter flows, into, out of, and within systems to understand system behavior
• Determining the relationships between structure and function
• Studying stability and change</td></tr>
<tr><th>Science Literacy</th><th>Science Lab Safety</th></tr>
<tr><td>• Producing clear and coherent technical writing in which the development, organization and style are appropriate for the science topic
• Correctly utilizing and explaining visually expressed information (e.g., flowchart, diagram, model, graph, table, or digital mapping technology) in a science narrative.
• Appropriately using technical terminology or scientific concepts and processes to create visually expressed information
• Reading with understanding articles about science in the popular press and engaging in social conversation about the validity of the conclusions
• Identifying scientific issues underlying national and local decisions and expressing positions that are scientifically and technologically informed
• Evaluating the quality and validity of scientific information on the basis of its source and the methods used to generate it.</td><td>• Requiring student lab safety training and demonstrating appropriate proficiency before participating in lab activities
• Archiving signed student safety contracts documenting lab safety training and medical contraindications (e.g., allergies, contact lenses, medical conditions)
• Wearing proper protective gear as needed (e.g., goggles, apron, and gloves)
• Requiring grade appropriate lab equipment operation and safety training
• Using and following SDS protocols
• Storing and disposing of chemical/biological materials properly
• Following ethical classroom uses of living materials/organisms
• Displaying proper safety signage and laboratory rules in the classroom and lab</td></tr>
</table>

Physical Science

Topic: Structure and Properties of Matter

S.C.5. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms in relation to:

- atomic size
- ionic size
- electronegativity
- ionization energy
- electron affinity

[Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.] [Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.]

<table>
<tr><th>Practices of Scientists and Engineers</th><th>Core Science Content</th></tr>
<tr><td>Constructing Explanations and Designing Solutions
Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. Students will use a model to predict the relationships between systems or between components of a system.</td><td rowspan="3">Structure and Properties of Matter
Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.</td></tr>
<tr><td>Science Connecting Concepts</td></tr>
<tr><td>Patterns
Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.</td></tr>
</table>

Observable features of the student performance by the end of the course:

1) Components of the model
   a) From the given model, students identify and describe* the components of the model that are relevant for their predictions, including:
      i) Elements and their arrangement in the periodic table;
      ii) A positively-charged nucleus composed of both protons and neutrons, surrounded by negatively-charged electrons;
      iii) Electrons in the outermost energy level of atoms (i.e., valence electrons); and
      iv) The number of protons in each element.
2) Relationships
   a) Students identify and describe* the following relationships between components in the given model, including:
      i) The arrangement of the main groups of the periodic table reflects the patterns of outermost electrons.
      ii) Elements in the periodic table are arranged by the numbers of protons in atoms.
3) Connections

a) Students use the periodic table to predict the patterns of behavior of the elements based on the attraction and repulsion between electrically charged particles and the patterns of outermost electrons that determine the typical reactivity of an atom.
b) Students predict the following patterns of properties:
   i) The number and types of bonds formed (i.e. ionic, covalent, metallic) by an element and between elements;
   ii) The number and charges in stable ions that form from atoms in a group of the periodic table;
   iii) The trend in reactivity and electronegativity of atoms down a group, and across a row in the periodic table, based on attractions of outermost (valence) electrons to the nucleus; and
   iv) The relative sizes of atoms both across a row and down a group in the periodic table.

Topic: Chemical Reactions

S.C.12. Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.] [Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.]

<table>
<tr><th>Practices of Scientists and Engineers</th><th>Core Science Content</th></tr>
<tr><td>Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, and peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will co</td><td rowspan="3">Structure and Properties of Matter
The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.

Chemical Reactions
The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.</td></tr>
<tr><td>Science Connecting Concepts</td></tr>
<tr><td>Patterns
Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.</td></tr>
</table>

Observable features of the student performance by the end of the course:

1) Articulating the explanation of phenomena
   a) Students construct an explanation of the outcome of the given reaction, including:
      i) The idea that the total number of atoms of each element in the reactant and products is the same;
      ii) The numbers and types of bonds (i.e., ionic, covalent) that each atom forms, as determined by the outermost (valence) electron states and the electronegativity;
      iii) The outermost (valence) electron state of the atoms that make up both the reactants and the products of the reaction is based on their position in the periodic table; and
      iv) A discussion of how the patterns of attraction allow the prediction of the type of reaction that occurs (e.g., formation of ionic compounds, combustion of hydrocarbons).
2) Evidence
   a) Students identify and describe* the evidence to construct the explanation, including:
      i) Identification of the products and reactants, including their chemical formulas and the arrangement of their outermost (valence) electrons;
      ii) Identification that the number and types of atoms are the same both before and after a reaction;
      iii) Identification of the numbers and types of bonds (i.e., ionic, covalent) in both the reactants and the products;
      iv) The patterns of reactivity (e.g., the high reactivity of alkali metals) at the macroscopic level as determined by using the periodic table; and
      v) The outermost (valence) electron configuration and the relative electronegativity of the atoms that make up both the reactants and the products of the reaction based on their position in the periodic table.

3) Reasoning
   a) Students describe* their reasoning that connects the evidence, along with the assumption that theories and laws that describe their natural world operate today as they did in the past and will continue to do so in the future, to construct an explanation for how the patterns of outermost electrons and the electronegativity of elements can be used to predict the number and types of bonds each element forms.
   b) In the explanation, students describe* the causal relationship between the observable macroscopic patterns of reactivity of elements in the periodic table and the patterns of outermost electrons for each atom and its relative electronegativity.
4) Revising the explanation
   a) Given new evidence or context, students construct a revised or expanded explanation about the outcome of a chemical reaction and justify the revision.

S.C.14. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. [Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students' use of mathematical thinking and not on memorization and rote application of problem-solving techniques.] [Assessment Boundary: Assessment does not include complex chemical reactions

Practices of Scientists and Engineers	Core Science Content
Using Mathematics and Computational Thinking Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. Students will use mathematical representations of phenomena to support claims.	Chemical Reactions The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
Science Connecting Concepts	
Energy and Matter The total amount of energy and matter in closed systems is conserved. Scientific Knowledge Assumes an Order and Consistency in Natural Systems Science assumes the universe is a vast single system in which basic laws are consistent.	

Observable features of the student performance by the end of the course:

1) Representation
   a) Students identify and describe* the relevant components in the mathematical representations:
      i) Quantities of reactants and products of a chemical reaction in terms of atoms, moles, and mass;
      ii) Molar mass of all components of the reaction;
      iii) Use of balanced chemical equation(s); and
      iv) Identification of the claim that atoms, and therefore mass, are conserved during a chemical reaction.

    b) The mathematical representations may include numerical calculations, graphs, or other pictorial depictions of quantitative information.
    c) Students identify the claim to be supported: that atoms, and therefore mass, are conserved during a chemical reaction.
2) Mathematical modeling
    a) Students use the mole to convert between the atomic and macroscopic scale in the analysis.
    b) Given a chemical reaction, students use the mathematical representations to
        i) Predict the relative number of atoms in the reactants versus the products at the atomic molecular scale; and
        ii) Calculate the mass of any component of a reaction, given any other component.
3) Analysis
    a) Students describe* how the mathematical representations (e.g., stoichiometric calculations to show that the number of atoms or number of moles is unchanged after a chemical reaction where a specific mass of reactant is converted to product) support the claim that atoms, and therefore mass, are conserved during a chemical reaction.
    b) Students describe* how the mass of a substance can be used to determine the number of atoms, molecules, or ions using moles and mole relationships (e.g., macroscopic to atomic molecular scale conversion using the number of moles and Avogadro’s number).

Topic: Applications of Chemical Reactions

S.C.24. Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.] [Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.]

Practices of Scientists and Engineers	Core Science Content
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. Students will construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, and peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.	Structure and Properties of Matter The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. Chemical Reactions The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
Science Connecting Concepts	
Patterns Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.	

Observable features of the student performance by the end of the course:

1) Articulating the explanation of phenomena
    a) Students construct an explanation of the outcome of the given reaction, including:
        i) The idea that the total number of atoms of each element in the reactant and products is the same;
        ii) The numbers and types of bonds (i.e., ionic, covalent) that each atom forms, as determined by the outermost (valence) electron states and the electronegativity;
        iii) The outermost (valence) electron state of the atoms that make up both the reactants and the products of the reaction is based on their position in the periodic table; and
        iv) A discussion of how the patterns of attraction allow the prediction of the type of reaction that occurs (e.g., formation of ionic compounds, combustion of hydrocarbons).
2) Evidence
    a) Students identify and describe* the evidence to construct the explanation, including:
        i) Identification of the products and reactants, including their chemical formulas and the arrangement of their outermost (valence) electrons;
        ii) Identification that the number and types of atoms are the same both before and after a reaction;
        iii) Identification of the numbers and types of bonds (i.e., ionic, covalent) in both the reactants and the products;
        iv) The patterns of reactivity (e.g., the high reactivity of alkali metals) at the macroscopic level as determined by using the periodic table; and
        v) The outermost (valence) electron configuration and the relative electronegativity of the atoms that make up both the reactants and the products of the reaction based on their position in the periodic table.

3) Reasoning
   a) Students describe* their reasoning that connects the evidence, along with the assumption that theories and laws that describe their natural world operate today as they did in the past and will continue to do so in the future, to construct an explanation for how the patterns of outermost electrons and the electronegativity of elements can be used to predict the number and types of bonds each element forms.
   b) In the explanation, students describe* the causal relationship between the observable macroscopic patterns of reactivity of elements in the periodic table and the patterns of outermost electrons for each atom and its relative electronegativity.
4) Revising the explanation
   a) Given new evidence or context, students construct a revised or expanded explanation about the outcome of a chemical reaction and justify the revision.

S.C.26. Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay. [Clarification Statement: Emphasis is on simple qualitative models, such as pictures or diagrams, and on the scale of energy released in nuclear processes relative to other kinds of transformations.] [Assessment Boundary: Assessment does not include quantitative calculation of energy released. Assessment is limited to alpha, beta, and gamma radioactive decays.]

Practices of Scientists and Engineers	Core Science Content
Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. Students will develop a model based on evidence to illustrate the relationships between systems or between components of a system.	**Nuclear Processes** Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process.
Science Connecting Concepts	
Energy and Matter In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved.	

Observable features of the student performance by the end of the course:

1) Components of the model
   a) Students develop models in which they identify and describe* the relevant components of the models, including:
      i) Identification of an element by the number of protons;
      ii) The number of protons and neutrons in the nucleus before and after the decay;
      iii) The identity of the emitted particles (i.e., alpha, beta — both electrons and positrons, and gamma); and
      iv) The scale of energy changes associated with nuclear processes, relative to the scale of energy changes associated with chemical processes.
2) Relationships
   a) Students develop five distinct models to illustrate the relationships between components underlying the nuclear processes of 1) fission, 2) fusion and 3) three distinct types of radioactive decay.
   b) Students include the following features, based on evidence, in all five models:

i) The total number of neutrons plus protons is the same both before and after the nuclear process, although the total number of protons and the total number of neutrons may be different before and after.
ii) The scale of energy changes in a nuclear process is much larger (hundreds of thousands or even millions of times larger) than the scale of energy changes in a chemical process.

3) Connections
   a) Students develop a fusion model that illustrates a process in which two nuclei merge to form a single, larger nucleus with a larger number of protons than were in either of the two original nuclei.
   b) Students develop a fission model that illustrates a process in which a nucleus splits into two or more fragments that each have a smaller number of protons than were in the original nucleus.
   c) In both the fission and fusion models, students illustrate that these processes may release energy and may require initial energy for the reaction to take place.
   d) Students develop radioactive decay models that illustrate the differences in type of energy (e.g., kinetic energy, electromagnetic radiation) and type of particle (e.g., alpha particle, beta particle) released during alpha, beta, and gamma radioactive decay, and any change from one element to another that can occur due to the process.
   e) Students develop radioactive decay models that describe* that alpha particle emission is a type of fission reaction, and that beta and gamma emission are not.

S.C.27. Communicate scientific and technical information about why the molecular-level structure and shape is important in the functioning of designed materials in reference to:

- polymers
- plastics
- pharmaceuticals
- vaccines.

[Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.] [Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.]

<table>
<tr><th>Practices of Scientists and Engineers</th><th>Core Science Content</th></tr>
<tr><td>Obtaining, Evaluating, and Communicating Information
Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs. Students will communicate scientific and technical information (e.g., about the process of development and the design and performance of a proposed process or system) in multiple formats (including oral, graphical, textual and mathematical).</td><td rowspan="3">Types of Interactions
Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.</td></tr>
<tr><td>Science Connecting Concepts</td></tr>
<tr><td>Structure and Function
Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.</td></tr>
</table>

Observable features of the student performance by the end of the course:

1) Communication style and format
    a) Students use at least two different formats (including oral, graphical, textual and mathematical) to communicate scientific and technical information, including fully describing* the structure, properties, and design of the chosen material(s). Students cite the origin of the information as appropriate.
2) Connecting the content and the science connecting concepts
    a) Students identify and communicate the evidence for why molecular level structure is important in the functioning of designed materials, including:
        i) How the structure and properties of matter and the types of interactions of matter at the atomic scale determine the function of the chosen designed material(s); and
        ii) How the material's properties make it suitable for use in its designed function.
    b) Students explicitly identify the molecular structure of the chosen designed material(s) (using a representation appropriate to the specific type of communication — e.g., geometric shapes for drugs and receptors, ball and stick models for long-chained molecules).
    c) Students describe* the intended function of the chosen designed material(s).
    d) Students describe* the relationship between the material's function and its macroscopic properties (e.g., material strength, conductivity, reactivity, state of matter, durability) and each of the following:
        i) Molecular level structure of the material;
        ii) Intermolecular forces and polarity of molecules; and
        iii) The ability of electrons to move relatively freely in metals.
    e) Students describe* the effects that attractive and repulsive electrical forces between molecules have on the arrangement (structure) of the chosen designed material(s) of molecules (e.g., solids, liquids, gases, network solid, polymers).
    f) Students describe* that, for all materials, electrostatic forces on the atomic and molecular scale results in contact forces (e.g., friction, normal forces, stickiness) on the macroscopic scale.

Engineering, Technology, and Applications of Science

Topic: Engineering Design

S.C.28. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

Practices of Scientists and Engineers	Core Science Content
Asking Questions and Defining Problems Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations. Students will analyze complex real-world problems by specifying criteria and constraints for successful solutions.	**Defining and Delimiting Engineering Problems** Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. • Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.
Science Connecting Concepts	
Influence of Science, Engineering, and Technology on Society and the Natural World New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.	

Observable features of the student performance by the end of the course:

1) Identifying the problem to be solved
   a) Students analyze a major global problem. In their analysis, students:
      i) Describe the challenge with a rationale for why it is a major global challenge;
      ii) Describe, qualitatively and quantitatively, the extent and depth of the problem and its major consequences to society and/or the natural world on both global and local scales if it remains unsolved; and
      iii) Document background research on the problem from two or more sources, including research journals.
2) Defining the process or system boundaries, and the components of the process or system
   a) In their analysis, students identify the physical system in which the problem is embedded, including the major elements and relationships in the system and boundaries so as to clarify what is and is not part of the problem.
   b) In their analysis, students describe societal needs and wants that are relative to the problem (e.g., for controlling CO_2 emissions, societal needs include the need for cheap energy).
3) Defining the criteria and constraints
   a) Students specify qualitative and quantitative criteria and constraints for acceptable solutions to the problem

S.C.29 Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Practices of Scientists and Engineers	Core Science Content
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories. Students will design a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.	**Optimizing the Design Solution** Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed.
Science Connecting Concepts	

Observable features of the student performance by the end of the course:

1) Using scientific knowledge to generate the design solution
   a) Students restate the original complex problem into a finite set of two or more sub-problems (in writing or as a diagram or flow chart).
   b) For at least one of the sub-problems, students propose two or more solutions that are based on student-generated data and/or scientific information from other sources.
   c) Students describe how solutions to the sub-problems are interconnected to solve all or part of the larger problem.
2) Describing criteria and constraints, including quantification when appropriate
   a) Students describe criteria and constraints for the selected sub-problem.
   b) Students describe the rationale for the sequence of how sub-problems are to be solved, and which criteria should be given highest priority if tradeoffs must be made.

S.C.30 Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Practices of Scientists and Engineers	Core Science Content
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories. Students will evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.	**Developing Possible Solutions** When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.
Science Connecting Concepts	
Influence of Science, Engineering, and Technology on Society and the Natural World New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.	

Observable features of the student performance by the end of the course:

1) Evaluating potential solutions

    a) In their evaluation of a complex real-world problem, students:
        i) Generate a list of three or more realistic criteria and two or more constraints, including such relevant factors as cost, safety, reliability, and aesthetics that specifies an acceptable solution to a complex real-world problem;
        ii) Assign priorities for each criterion and constraint that allows for a logical and systematic evaluation of alternative solution proposals;
        iii) Analyze (quantitatively where appropriate) and describe the strengths and weaknesses of the solution with respect to each criterion and constraint, as well as social and cultural acceptability and environmental impacts;
        iv) Describe possible barriers to implementing each solution, such as cultural, economic, or other sources of resistance to potential solutions; and
        v) Provide an evidence-based decision of which solution is optimum, based on prioritized criteria, analysis of the strengths and weaknesses (costs and benefits) of each solution, and barriers to be overcome.

2) Refining and/or optimizing the design solution
    a) In their evaluation, students describe which parts of the complex real-world problem may remain even if the proposed solution is implemented.

S.C.31. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Practices of Scientists and Engineers	Core Science Content
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. Students will use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems.	Developing Possible Solutions Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.
Science Connecting Concepts	
Systems and System Models Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions — including energy, matter, and information flows — within and between systems at different scales.	

Observable features of the student performance by the end of the course:

1) Representation

a) Students identify the following components from a given computer simulation:
   i) The complex real-world problem with numerous criteria and constraints;
   ii) The system that is being modeled by the computational simulation, including the boundaries of the systems;
   iii) What variables can be changed by the user to evaluate the proposed solutions, tradeoffs, or other decisions; and
   iv) The scientific principle(s) and/or relationship(s) being used by the model.

2) Computational Modeling
   a) Students use the given computer simulation to model the proposed solutions by:
      i) Selecting logical and realistic inputs; and
      ii) Using the model to simulate the effects of different solutions, tradeoffs, or other decisions.
3) Analysis
   a) Students compare the simulated results to the expected results.
   b) Students interpret the results of the simulation and predict the effects of the proposed solutions within and between systems relevant to the problem based on the interpretation.
   c) Students identify the possible negative consequences of solutions that outweigh their benefits.
   d) Students identify the simulation's limitations.

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