The Journal of Economic Education

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/vece20

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To cite this article: Stephen L. Chew & William J. Cerbin (2020): The cognitive challenges of effective teaching, The Journal of Economic Education

To link to this article: https://doi.org/10.1080/00220485.2020.1845266

Published online: 30 Nov 2020.

THE JOURNAL OF ECONOMIC EDUCATION
https://doi.org/10.1080/00220485.2020.1845266

Routledge
Taylor & Francis Group

FEATURES AND INFORMATION
Applying Cognitive Science to Economic Education

The cognitive challenges of effective teaching

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ABSTRACT
The authors describe a research-based conceptual framework of how students learn that can guide the design, implementation, and troubleshooting of teaching practice. The framework consists of nine interacting cognitive challenges that teachers need to address to enhance student learning. These challenges include student mental mindset, metacognition and self-regulation, student fear and mistrust, prior knowledge, misconceptions, ineffective learning strategies, transfer of learning, constraints of selective attention, and the constraints of mental effort and working memory. The challenges are described with recommendations on how to address each one. What is effective for one situation may not be effective in others, and no single teaching method will always be optimal for all teachers, students, topics, and educational contexts. The teacher's task is to manage this complex interaction successfully.

KEYWORDS
Pedagogy; science of learning; teaching improvement

JEL CODES
A20, A22, A23

> If you ask many academics how they define teaching, they will often talk about transmitting knowledge, as if teaching *is* telling … To benefit from what the best teachers do, however, we must embrace a different model, one in which teaching occurs only when learning takes place … [T]eaching in this conception is creating those conditions in which most—if not all—of our students will realize their potential to learn. (*What the Best College Teachers Do* [Bain 2004, 173])

The past 20 years have seen an outpouring of research on how to design teaching more effectively to promote student learning. Student learning is remarkably complex, and teachers need to understand this complexity in order to design maximally effective pedagogy. The standard view of teaching is that teachers explain information and design activities for students. Students listen and engage in these activities and, according to their level of ability and motivation, they achieve some level of learning. We know now that this view is simplistic (Nuthall 2007). Capable students may fail to learn because they use poor learning strategies, or they lack sufficient prior knowledge to understand the concepts, or they mistakenly believe that they have understood the concepts, but they have not, or instead of learning, they cling to misconceptions that they held before taking the class. Students may complete all of the activities successfully but be so overwhelmed by the effort that they learn nothing from them, or they may learn information but never think of it or apply it beyond the exam. The purpose of this article is to synthesize the current research on student learning into a single framework that teachers can use to improve their teaching and enhance student learning.

Pedagogical research falls into three broad, overlapping categories. First are studies from cognitive psychology, the subfield of psychology that studies mental processes such as attention,

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learning, and memory. This approach generally uses controlled, often laboratory-based, studies with careful manipulations of a limited number of factors such as learning strategies or attention (e.g., Bransford, Brown, and Cocking 1999; Benassi, Overson, and Hakala 2014; Weinstein, Sumeracki, and Caviglioli 2019). The second category is educational research, which studies factors such as teacher and student characteristics that affect learning in actual educational settings (e.g., Hattie 2009; Nuthall 2007). This kind of research tends to be less controlled but more authentic in teaching context. The final category is the study of master teachers (e.g., Bain 2004; Keeley, Ismail, and Buskist 2016). Researchers identify teachers who are widely regarded by faculty peers and students as extraordinarily effective teachers. Researchers then generally use qualitative methods to describe the traits and practices of these teachers compared to regular teachers.

From these different lines of research, we can discern three common themes. The first theme is highlighted by Bain (2004) in the quote above. Teaching is not about "telling" or presenting information; it is about creating an environment in which most, if not all, students can learn. The focus of teaching should not be on how well we present information, but on how well we create conditions in which most students are able to learn. Second, effective teaching is about adaptation to changing circumstances. Students come to our classes with different goals and expectations, different levels of interest, and different levels of prior knowledge. Our teaching must adapt to these varying conditions. The third theme is that effective teaching involves translating cognitive principles of learning into pedagogical practice. Teachers need to understand how people learn and incorporate those principles into their teaching. Bain (2004) said this about the master teachers he studied:

> [T]he people we analyzed have generally cobbled together from their own experiences working with students, conceptions of human learning that are remarkably similar to some ideas that have emerged in the research and theoretical literature on cognition, motivation, and human development. (25)

Effective teaching involves an accurate understanding of the cognitive principles of learning. Although that sounds straightforward, many teachers underestimate the complexity of effective teaching (Chew et al. 2018) or base their pedagogy on misconceptions, untested intuitions, and false assumptions (Howard-Jones 2014).

Effective teaching and optimal learning

The goals of pedagogical research, and the cognitive framework we describe later, are effective teaching and optimal student learning. Here is what we mean by these goals. First, what is effective teaching? Consider the kinds of students we teach. Some students are keenly interested in our class and already have a strong foundation on the topic. Others have little to no background knowledge, or may even have misconceptions; they may have no inherent interest in the topic but are taking the course because it fits their schedule and fulfills a requirement. Some students are ready to work hard to excel, and some want to get by with minimal work. Some students will learn almost regardless of the teacher; for others, teaching presents a greater challenge. Successfully teaching knowledgeable, highly motivated students takes a minimum of competence in teaching. Effective, skilled teaching involves reaching as many of the less knowledgeable, less motivated students as possible, and developing them into well-informed, keen learners of our discipline. It involves creating an atmosphere in which learning becomes important to the student and achievable with sufficient effort. It is tempting to look at only students who are already primed to learn from anyone and consider our teaching successful. The preponderance of pedagogical research shows that effective teachers can reach many more students if the teachers understand the principles of learning.

To be clear, we are not saying that student learning is solely the responsibility of the teacher, nor are we arguing that the individual differences among students are so great that teaching is impossible. Students are responsible for determining the best way to learn from each teacher they have. The actions of the teacher can affect how easily students can accomplish this task as well as their motivation and perseverance. Furthermore, teachers adapt to their academic setting so that they develop strategies that are most likely to be effective with the students they encounter (Daniel and Poole 2009).

Now consider what we mean by optimal learning. Teachers often define learning as scoring well on an exam, but students can learn material well enough to make a good score on exams and then quickly forget the material afterward. Students may apply concepts within our courses, but fail to see any relevance beyond getting a good grade. After the course is over, they never think about the topic again or revert to popular misconceptions. On the other hand, students may embrace what they have learned and transform how they think about the world. These students might contact us after the course is over to tell us that they saw or read something, and it reminded them of our class. This latter scenario is optimal learning, the result of effective teaching. How can we promote optimal learning in our courses? Essentially, teachers need to be intentional in creating a learning environment based on cognitive principles that promote generalization and application of the knowledge beyond the course—a concept referred to as *far transfer* (Agarwal and Bain 2019). Teaching for transfer is one of the nine cognitive challenges in the framework. During the course, teachers can use formative assessments and feedback to both check and develop student understanding (e.g., Angelo and Cross 1993; Barkley and Major 2016). The goal is to build toward *authentic assessment*, in which students are given a problem or scenario that has meaningful similarities to situations they might encounter in a natural context (Gulikers, Bastiaens, and Kirschner 2004). Feedback from authentic assessments gives teachers feedback about the student's level of optimal learning. Students generally cannot make the leap from their first encounter with a concept to full understanding. Their learning needs to be developed through a cycle of formative assessment and effective feedback (Hattie and Timperley 2007; Nicol and Macfarlane 2006). Once again, it is tempting to be satisfied with the learning defined solely by test scores, but our goal as teachers should be optimal learning.

The cognitive framework described below is intended to help teachers achieve effective teaching and promote optimal student learning. The framework is extensive, consisting of nine challenges that teachers need to consider in their pedagogy. Each challenge embodies an important aspect of teaching. The framework shows that teaching is a complex skill that takes years to master. Research clearly shows the importance of each aspect. While it may not be necessary to address all aspects in an optimal manner to achieve effective teaching, each one has to be addressed with some level of success. Perhaps, more importantly, failure in any of the challenges can undermine teaching and learning.

The framework: the cognitive challenges to student learning[1]

This framework translates pedagogical research into a set of nine cognitive challenges that teachers need to address in order to help students learn. Ours is not the first attempt to specify a set of research-based principles to guide effective teaching. Rosenshine (2012), for example, listed a set of principles for effective instruction, which includes the following: provide models, guide student practice, and provide scaffolds for difficult tasks. These are sound advice, but they are also open to wide interpretation. What constitutes a good model? What is the goal of practice? How do we design good scaffolds for difficult tasks?

We believe our framework has two advantages over prior attempts. First, this framework is composed of cognitive *challenges* that teachers need to address, as opposed to a set of specified practices to follow. A cognitive challenge is a characteristic or aspect of mental processing that can affect the success or failure of learning. Teachers must determine the effective ways to resolve each challenge, but that solution may vary for different topics and students. Failure to navigate

Table 1. The cognitive challenges of effective teaching.

Challenge	Description
1. Student mental mindset	• Students hold attitudes and beliefs about a course or topic, such as how interesting or valuable it will be and how capable they are to master it through their own efforts. • Students may believe a course is irrelevant to them or that they lack the ability needed to learn the content.
2. Metacognition and self-regulation	• Students monitor and judge their level of understanding of concepts and they regulate their learning behaviors to achieve a desired level of mastery. • Students may be overconfident in their level of understanding.
3. Student fear and mistrust	• Students come to a course with a certain level of fear of taking it. Students may interpret the teacher's behavior as being unfair or unsupportive of their learning, resulting in a certain degree of mistrust. • Negative emotional reactions such as fear, or lack of trust in the teacher, can undermine motivation and interfere with learning.
4. Insufficient prior knowledge	• Students vary in how much they know about course content at the start of the course. • Some students may have little to no knowledge about the content, putting them at a disadvantage compared to students with a strong background.
5. Misconceptions	• Students often hold faulty or mistaken beliefs about the course content at the start of the course. • Students may cling to misconceptions even when taught accurate information.
6. Ineffective learning strategies	• Students can employ various methods to learn course concepts, and these methods vary widely in effectiveness and efficiency. • Students often prefer the least effective learning strategies.
7. Transfer of learning	• Students can vary in their ability and propensity to apply course concepts appropriately outside the classroom context. • Students often fail to apply knowledge beyond the end of a course.
8. Constraints of selective attention	• Students can focus their awareness on only a limited portion of the environment, missing anything outside that focus. • People mistakenly believe they can multitask, switching attention back and forth among different tasks.
9. Constraints of mental effort and working memory	• Students have two major limitations in cognitive processing, the amount of mental effort or concentration available to them and the ability to hold information consciously. • Students are easily overwhelmed by trying to concentrate on too complex a task, or to remember too much information.

any of the challenges can undermine optimal learning. Next, the proposed framework is contextual; the impact of any single component is influenced by the other components (Chew et al. 2009; Daniel and Poole 2009; McDaniel and Butler 2011; Daniel and Chew 2013; Schneider and Preckel 2017). Prior knowledge of a concept, for example, strongly influences how easily students can learn more about that concept (Ambrose and Lovett 2014). Thus, teaching strategies that are effective for students with rich prior knowledge of a topic may not be effective for students with little to no prior knowledge. All teachers need to adapt pedagogy to fit their own particular context. There is no single best teaching strategy for all students, topics, and situations. The proposed framework is not prescriptive, but diagnostic in nature, and can guide adaptation of teaching practice.

The framework

The nine cognitive challenges are listed in table 1, with a brief description of each that includes the cognitive process involved and how the process can undermine learning. They are in no particular order of importance.

Each cognitive challenge will now be described in more detail, with a student example, a description of the challenge, possible solutions for addressing the challenge, and recommended resources and readings about the challenge.

Challenge 1: student mental mindset

Student example. A student is required to take calculus for her major. The student dreads it because her past negative experiences with math have convinced her that she has little math ability and hates studying math.

Description of the challenge. Mental mindset refers to the students' attitudes, beliefs, and expectations about a course or subject (Farrington 2013; Chew 2014). Mental mindset encompasses the teacher, course, topic, pedagogy, method of assessment, and beliefs about the likelihood of their success in the course through their own efforts. Students come into a class with preconceived notions of how valuable the course will be to them, how important the course is compared to other courses they are taking, how hard the course will be for them, and what is a reasonable workload for the course. For example, Cahill et al. (2018) found that student attitudes toward physics predicted student learning across different topics, courses, teaching styles, and assessments, even after controlling for prior knowledge.

Dweck and colleagues have explored the impact of implicit theories of intelligence on learning (Yeager and Dweck 2012; Yeager et al. 2019). Implicit theories fall along a spectrum. At one extreme are entity or fixed theories, which hold that intelligence or ability is set and unchangeable through personal effort. Students with fixed mindsets see effort as a sign of weakness, and they avoid challenges because failure cannot be overcome through effort. A fixed mindset undermines resilience in the face of setbacks. On the other end of the spectrum are incremental or growth mindsets. Students with growth mindsets see intellectual ability as a malleable trait that can be cultivated and enhanced through personal effort. Students with growth mindsets are more likely to embrace intellectual challenges as opportunities to learn and grow, and they are more likely to be resilient in the face of setbacks. Growth or incremental mindset is likely related to the concept of academic self-efficacy (Zimmerman 2000), which refers to students' belief in their own capability to learn. Academic self-efficacy is strongly linked to learning and motivation.

In a review of the K–12 literature, Farrington (Farrington 2013; Farrington et al. 2012) concluded that academic mindset was a crucial factor in promoting student engagement and perseverance. They identified four student beliefs that contribute to a successful mindset: (1) "*I belong in this academic community.*" (2) "*I can succeed at this.*" (3) "*My ability and competence grow with my effort.*" (4) "*This work has value for me.*" (Farrington 2013, 5–7) The second and third beliefs correspond to growth mindset. The first belief reflects the importance of a sense of belongingness and is related to student fear and mistrust discussed below.

Recommendations. Teachers should promote the four beliefs that constitute a successful mindset listed above (Farrington 2013). For example, teachers should explain the value and importance of the class to students from the first day, whether it be for their majors, careers, or for general education.

There is good evidence that a fixed mindset can be changed to a more constructive growth mindset through targeted interventions or effective pedagogy. The PERTS (Project for Education Research that Scales) Lab offers a free online course for students called "Growth Mindset for College Students" through its Web site (www.perts.net). The course takes about 30 minutes and is shown to be effective in promoting student perseverance. Yeager et al. (2016) discuss how to design interventions for promoting a growth mindset. Active learning strategies that enhance student achievement improve academic self-efficacy (Ballen et al. 2017). Formative assessments can promote both growth mindset and academic self-efficacy (Yin et al. 2008). Mindset is related to the challenges of misconceptions and to student fear and mistrust.

Recommended reading. The PERTS Lab offers a free online course for instructors called "The Mindset Kit" that explains all aspects of growth mindset, including teaching students about mindset, helping students learn from mistakes, and promoting belongingness. That course and other resources are found on the PERTS Web site (www.perts.net/).

- Farrington and colleagues (Farrington 2013; Farrington et al. 2012) have written two extensive literature reviews on so-called noncognitive factors and their impact on learning, including mindset.

Challenge 2: metacognition and self-regulation

Student example. A student feels confident going into the first exam in introductory psychology because the lectures always made sense to him and the material didn't seem complicated. He skimmed over his notes and the textbook and was familiar with all the major concepts. He felt pretty good taking the exam, but when he gets the exam score back, he is shocked to find he failed.

Description of the challenge. Metacognition refers to one's awareness of and ability to regulate one's own thinking (Flavell 1979). Effective metacognitive awareness is like an internal monitor that notices when a person's attention wanes, when they have or have not mastered a concept adequately, when their thinking is faulty, or when there are gaps in understanding. Metacognition is the basis for self-regulated learning, which enables students to plan, apply strategies, monitor, evaluate, and adjust their learning (Ambrose et al. 2010).

Students differ widely with respect to their metacognitive knowledge. For example, students often have erroneous beliefs that undermine their learning, and many students are not able to judge their own learning accurately (Morehead, Rhodes, and DeLozier 2016; Bjork, Dunlosky, and Kornell 2013; Kornell and Finn 2016). Research also shows that students have difficulty regulating their own learning.

Recommendations. To support better self-regulated learning, instructors can use reflective assignments related to planning, monitoring, and adjusting one's learning. For example, to help students understand assignments and course expectations, teachers can ask them to explain what they think assignments expect them to do and submit study plans for test preparation (Winkelmes et al. 2016). To support students' reflection and self-evaluation, Lovett (2013) recommends using "exam wrappers" in which students answer questions about how they planned, prepared, and studied for a test (or assignment), and what they would do to improve their learning on future tasks.

A technique to promote more accurate judgments of their learning involves administering a challenging practice test a week before the actual course exam. Students then use corrective feedback to analyze their performance and also describe how they plan to study for the upcoming exam. This strategy is an opportunity to practice self-evaluation and use the information to adjust their study before a high-stakes test.

Recommended reading. For an overview of metacognition research, see Girash (2014),[2] For research on how problematic metacognition can affect student learning and strategies for promoting effective metacognition, see Ehrlinger and Shain (2014).[3] Cerbin (2015)[4] reviews strategies teachers can use to promote accurate metacognitive awareness and self-regulated learning. Tanner (2012)[5] describes strategies to support student metacognition in undergraduate biology courses, which can be adapted to other disciplines.

Challenge 3: student fear and mistrust

Student example. A student is the first in her family to attend college and is unfamiliar with college-level academic work and expectations. She is enrolled in the first-year English composition class. The instructor warns the class that the course will be hard and many of them will struggle. When the student receives negative feedback on her first essay, she assumes the professor is trying to "weed out" weak students like her. She does not seek help from the instructor and stops going to class.

Description of the challenge. Fear is a negative emotional response to a specific, observable situation. Whether the situation poses a real or perceived threat does not matter. Anxiety, on the other hand, is a more diffuse negative emotional response to some possible future event. Students may have math anxiety, but they fear taking a required calculus course. Cox (2011) showed that student fear can cause students and teachers to misunderstand each other's actions and motives to the detriment of student success. Students do not see the point of some required general education or introductory courses other than to make them feel unwelcome or weed them out. Student mistrust can cause students to see critical feedback as evidence of the teacher's bias, hostility, or indifference, and the students may simply ignore the feedback (Yeager et al. 2014). One remedy for student fear is student trust in the teacher.

Student trust in the teacher is defined as students' willingness to take risks based on their judgment that the teacher is committed to student success (Chew et al. 2018). Trust can be broken down into three components: competence, integrity, and beneficence. Competence means that the teacher is knowledgeable and sufficiently skilled to teach effectively. Integrity means that the teacher acts truthfully, reliably, and responsibly. The teacher sets fair policies and deadlines and sticks to them. The teacher treats students with respect. Finally, beneficence is when the teacher's actions, such as course assignments and grading policies, have the students' best interests in mind. That doesn't mean that the assignments will be easy, but that they will be worthwhile in terms of student growth and learning. Students trust that the teacher will provide the help and resources they need.

Cavanagh et al. (2018) found that student trust predicted students' willingness to engage in more difficult active learning activities. Similarly, Chew et al. (2018) found that trust in the teacher improves students' willingness to give their best effort and take on more challenging assignments. Fryberg, Covarrubias, and Burack (2013) found that trust in the teacher is especially important for students from more interdependent cultures, such as Native American students, compared to European American students.

Research shows that fear is common among students who feel vulnerable or marginalized, such as Black students at predominantly White institutions (Guiffrida and Douthit 2010), undocumented Latina and Latino students (Pérez et al. 2010), and first-generation college students (Stephens, Hamedani, and Destin 2014). It is likely that fear will be more prevalent and trust will be more important in any situation in which students feel vulnerable, such as students who are taking courses they see as having a high risk for failure.

Recommendations. Yeager et al. (2014) found that trust significantly improved motivation and perseverance among minority students. They used a *wise feedback* intervention to improve trust. Wise feedback is when students are given feedback on an assignment, but the nature of the feedback conveys three messages to the student. The feedback is a reflection of the teacher's high standards and not bias, the teacher believes the student is capable of accomplishing those standards, and the teacher is willing to provide the resources the student needs to achieve those standards. Students completed an essay writing assignment for a class, and the teachers provided critical feedback. African American students who received the wise feedback intervention were significantly more likely to revise and resubmit their essays compared to the control group. The effect was larger for African American students than White students who showed a nonsignificant increase in the rate of revision and resubmission.

Students benefit from learning about successful students who have succeeded in the program from similar backgrounds. Stephens, Hamedani, and Destin (2014) designed an intervention where first-generation students learned about senior students from backgrounds like theirs who had succeeded. The students were shown how their background could be a source of strength if they followed strategies that would help them be successful. The intervention led to a significant reduction in anxiety and a higher GPA compared to students in the control condition.

Cognitive reappraisal interventions are easy to do and show promise in reducing anxiety and improving learning. On the night before a major exam in general psychology, Brady, Hard, and Gross (2018) sent students either a reappraisal message or a standard message of encouragement. In the reappraisal message, students were told that stress before an exam is both normal and helpful. They should see the stress as a way of helping them do their best on the exam. The reappraisal message led to significantly higher exam scores among first-year students with high test anxiety.

Two other factors also can reduce student fear and mistrust. Belongingness refers to the sense that a person has social connections with a social group. A sense of belongingness within a class is a major determinant of achievement motivation and perseverance (e.g., Walton et al. 2012). Rapport refers to a student-teacher relationship in which the student finds the teacher warm, approachable, and supportive of students. The teacher listens to students and is open to their points of view. Rapport is related to positive student attitudes toward an instructor and class as well as desirable student outcomes (e.g., Wilson, Ryan, and Pugh 2010).

To promote student trust, teachers should exhibit competence, integrity, and a commitment to helping students learn and succeed in all aspects of the course, including the course syllabus, course policies, lessons and assignments, grading, and interactions with students. For example, a teacher can give a midterm course evaluation, share the results, and make any needed changes. Teachers should explain how course decisions are grounded in fairness, integrity, and the best interest of the whole class. To build a sense of belongingness and rapport, teachers should show interest in getting to know the students. Teachers should be approachable, make themselves available to students, and invite students to speak with them individually, especially if the students are doing well or doing poorly. Teachers should be respectful in student interactions and be careful not to single any student out or show favoritism.

Recommended readings. For an extensive case study in how fear and mistrust can undermine student performance, we recommend *The College Fear Factor* (Cox 2011). Both the student and teacher may enter a class with good intentions, but fear can cause misunderstanding and miscommunication, leading to poor experiences for both teacher and student. For interventions that build trust and reduce anxiety, see Yeager et al. (2014) and Brady, Hard, and Gross (2018), respectively.

Challenge 4: insufficient prior knowledge

Student example. A student graduated from a high school that did not offer calculus. Now she has to take calculus for her major. She is having a hard time understanding the concepts and keeping up with the rapid pace of the class. Many of the other students took calculus in high school. They have seen most of the concepts previously and this course is more of a refresher for them.

Description of the challenge. Possessing accurate and sufficient prior knowledge typically facilitates new learning (Ambrose et al. 2010). Relevant prior knowledge is the foundation on which new learning is built. Insufficient prior knowledge is a significant cause of learning difficulties.

Gaps in relevant background knowledge make it more difficult to interpret, organize, and remember new information (Bransford, Brown, and Cocking 1999).

Insufficient prior knowledge may occur when students lack prerequisite courses, but a more common cause of insufficient background knowledge is students' lack of class preparation. More than half of freshmen and seniors report they come to class unprepared sometimes, and an additional 19 percent report being unprepared often or very often (NSSE 2016, 2017).

Recommendations. Students benefit from prior knowledge assignments that target relevant knowledge for each class period. To enhance students' prior knowledge, teachers have used online practice quizzes before class, pre-class reading assignments with embedded questions, and in-class review quizzes of relevant material at the start of class (Nguyen and McDaniel 2014; Stiegler-Balfour et al. 2014; Grimaldi and Karpicke 2012; Khanna 2015).

Studies of these techniques have found that students are more likely to complete practice quizzes and reading quizzes if they are low stakes. In these studies, teachers assigned a small amount of course credit for completing the quizzes (Agarwal et al. 2018; Lyle and Crawford 2011).

Recommended reading. Ambrose and Lovett (2014)[6] examine the types of prior knowledge problems common in college classes. Shortcomings in prior knowledge can be addressed by promoting the use of potent learning techniques for learning from text. Nguyen and McDaniel (2014)[7] and Stiegler-Balfour et al. (2014)[8] both discuss ways to help students outside the classroom to develop appropriate prior knowledge in their courses.

Challenge 5: misconceptions

Student example. A student who did poorly on the first exam visits the instructor. "The problem," the student says, "is that you explain everything to us using words. I'm more of a visual learner and not an auditory learner. You need to use more pictures and diagrams in your lecturing so people like me can learn better."

Description of the challenge. Learning involves using prior knowledge to help make sense of and learn new information (Bransford, Brown, and Cocking 1999). When students' prior knowledge is inaccurate, they are more likely to misinterpret, misunderstand, or even disregard new information. Inaccurate prior knowledge—or misconceptions—can be remarkably resistant to correction and a significant barrier to new learning (Chi 2013; Taylor and Kowalski 2014).

Misconceptions are common occurrences, formed by exposure to inaccurate information, faulty reasoning, or by misinterpreting information (Lilienfeld 2010; Murphy and Alexander 2013). Some misconceptions are minor errors in understanding that can be corrected easily or that students may resolve on their own. A more difficult problem is that some misconceptions are resistant to change and significant barriers to new learning (Schwartz, Tsang, and Blair 2016b). In some cases, students appear to overcome misconceptions during a course, but then revert back to them after the course is over (Clement 1982). The example above illustrates the myth of learning styles, the misconception that people have a single, preferred mode of learning, such as visual, auditory, or kinesthetic. Despite research debunking learning styles and theoretical critiques, the myth of learning styles remains common in educational settings (Pashler et al. 2008).

Deep misconceptions are difficult to correct, and simply presenting accurate information to students may not change them (Chi 2013; Taylor and Kowalski 2014). Busom, Lopez-Mayan, and Panadés (2017) examined a variety of student misconceptions in introductory economics classes and found

> … that exposure to an economic principles course and doing well in exams and coursework hardly seems to affect misconceptions. This suggests that standard teaching practices may not be sufficiently effective in having students integrate the tools of economic analysis into their reasoning processes, and consequently on their judgments and decisions. (84)

Recommendations. Diagnostic tests can help teachers identify students' misconceptions. For example, Goffe (2013), Bice et al. (2014), and Busom, Lopez-Mayan, and Panadés (2017) have developed surveys that measure students' preconceptions of economic principles. By identifying the nature and prevalence of student misconceptions in their classes, teachers can be more aware of how students misunderstand specific concepts and plan instruction accordingly.

Refutational teaching has shown promising positive results in changing students' misconceptions. In this approach, students first read refutational texts that explain and contradict their misconceptions, followed next by a refutational lecture in which the instructor explicitly refutes the misconception. Research has shown that, in some cases, refutational texts alone can prompt a change in student misconceptions. If not, the second part of the strategy involves a lecture and explanation by the instructor that reinforces the text and refutes the misconception (Taylor and Kowalski 2014).

Predict-observe-explain (POE) is another strategy that can help students overcome misconceptions. In this three-step strategy, the instructor first presents a problem or scenario to the class and asks them to predict how the scenario will turn out, i.e., the outcome or result (prediction). Next, the instructor reveals the actual results (observe) and, last of all, asks students to explain the results and resolve any discrepancies between their predictions and the observed results (explain).

Students who predict outcomes before observing the results of a problem or class demonstration are much more likely to grasp the underlying concepts or principles on which the problem is based (Brod, Hasselhorn, and Bunge 2018). Moreover, students' predictions may reveal misconceptions, which can help the teacher give immediate corrective feedback.

In the final step of a POE episode, students try to explain or justify their reasoning, choices, decisions, and opinions, and reconcile these with the actual results of the scenario. Explaining is a potent strategy for elaborating and revising one's understanding (Chiu and Chi 2014). Moreover, instructors can give targeted feedback to highlight key points or give additional examples that illustrate the relevant concepts.

Recommended readings. Chew (2005) describes the problem of misconceptions and how to use ConcepTests and peer instruction to promote conceptual change in students. Taylor and Kowalski (2014)[9] expand on how to use refutational teaching to reduce student misconceptions.

Challenge 6: ineffective learning strategies

Student example. A student has done poorly on a test. She is upset because she wanted to do well and studied for many hours. Her approach was to read the textbook, highlight the key terms, and then re-read highlighted portions of the text.

Description of the challenge. Students underperform and learn less when they use ineffective learning strategies. Research indicates that college students vary in their knowledge and use of effective learning strategies, and often use ineffective strategies such as re-reading, highlighting, underlining, cramming and rote memorization (Blasiman, Dunlosky, and Rawson 2017).

Students do not use effective learning strategies for a variety of reasons. For example, they may be unaware of effective ways to study, believing that their current strategies are effective when they are not. They also may have difficulty changing study habits they have used for years, even when they are aware of better strategies.

Recommendations. Teachers can instruct students in effective study behaviors as part of the course (Chew 2014). There are many from which to choose (Dunlosky et al. 2013; Weinstein, Sumeracki, and Caviglioli 2019), and teachers can select strategies that fit their learning context. Furthermore, teachers can incorporate effective learning strategies such as elaboration and retrieval practice into their course activities. Using effective strategies as part of the course exposes students to them and gives them an opportunity to practice them and potentially adopt them.

Three strategies—practice testing, spaced practice, and self-explanation—have all been used successfully to improve student learning in a variety of courses (Dunlosky et al. 2013). Rawson, Dunlosky, and Sciartelli (2013) combined practice testing and spaced practice in an introductory class. During the semester, students took practice quizzes that were spaced apart to optimize learning. Quiz questions from early in the semester were repeated later in the term so they practiced multiple times. Students in the practice quiz section of the course scored more than a letter grade higher than students in the no quiz course section. In a statistics course, instructors gave a low-stakes quiz at the end of every class period. Exam scores were substantially higher in the low-stakes quiz section of the course than in a no quiz section. Moreover, students liked the procedure and believed it increased their learning (Lyle and Crawford 2011). In a study of self-explanation, medical students, who were prompted to generate self-explanations of cases were better able to diagnose unfamiliar cases than students who were not instructed to generate self-explanations (Chamberland et al. 2011).

Recommended reading. There are many good resources for improving student learning strategies. Dunlosky and Rawson (2015),[10] for example, wrote a teacher-ready review describing how to combine practice quizzes with successive relearning in a large introductory course. For information about the theory, research, and classroom applications related to the strategy of retrieval practice or self-testing, see Pyc, Agarwal, and Roediger (2014)[11] or Weinstein, Sumeracki, and Caviglioli (2019). For a similar discussion of spaced practice, see Carpenter (2014),[12] and for self-explanation, see Chiu and Chi (2014).[13]

Challenge 7: transfer of learning

Student example. In a research methods course, the teacher is surprised to find that students are not sure what standard deviations are. He knows that all the students have completed a statistics course that covered standard deviation because it is a prerequisite for research methods.

Description of the challenge. Transfer of learning, in which students apply what they have learned appropriately in novel contexts, is the gold standard of learning. All teachers want students to retain and use the information gained in a class after the final exam is completed, and beyond the immediate classroom context. Transfer, however, remains a difficult and elusive goal to achieve, with many approaches and only limited successes (Barnett and Ceci 2002; Day and Goldstone 2012). Much knowledge gained in courses remains inert; it is not accessed or used beyond the immediate context in which it was learned (Bransford, Brown, and Cocking 1999).

The theme of enhancing transfer is a longstanding issue in learning science (e.g., Perkins and Salomon 2012). What is clear is that teachers cannot take transfer for granted, even if students score well on exams. When students learn a concept, there is no assurance that they will then spontaneously apply this concept beyond the course context. Teachers should consider how to design pedagogy to promote transfer to relevant contexts. Researchers distinguish between near and far transfer (Agarwal and Bain 2019). Near transfer is learning a concept in one context and applying that knowledge in a similar context. Far transfer involves learning a concept in one context and applying that concept appropriately in a different context. For example, the first author teaches behavioral statistics. Toward the beginning of the semester, we cover the computation of standard deviations. Later in the course, students need standard deviations to compute a correlation. When a problem gives only raw data, some students invariably ask how they are supposed to compute the correlation without being given the standard deviation. They fail to apply their knowledge of how to compute standard deviations. That is a failure of near transfer. Later in their education, students take research methods. If students can interpret standard deviations based on their statistics course, it is an example of successful far transfer.

Recommendations. There is no guarantee of transfer, especially far transfer, but several teaching practices have been shown to promote at least near transfer. Teachers should use *expansive framing*, in which students play an active role in constructing and applying information (Engle et al. 2012). As part of expansive framing, teachers should model how they think about concepts and apply the concept to authentic examples. They should avoid *bounded framing*, in which students receive cut-and-dried information to learn. Teachers should present concepts in a way that is similar to how they expect students to use and apply the concepts—a process called *transfer appropriate processing* (Morris, Bransford, and Franks 1977). The nature of feedback the teacher gives to students after assessments is also critical for learning and transfer (Hattie and Timperley 2007; Nicol and Macfarlane 2006).

Retrieval practice, having students retrieve and apply information, is an effective means of promoting transfer, especially when the retrieval events are spaced over time (Agarwal and Bain 2019). The testing effect, in which students learn by taking frequent, typically low-stakes, tests over material, is also an effective means of enhancing transfer (Son and Rivas 2016; Veltre, Cho, and Neely 2015), although the kinds of questions used to test knowledge are important. The questions should promote reasoning and application in novel, but still similar, contexts. Both retrieval practice and testing can be accomplished through formative assessment, which means that assessment can be designed to both measure and promote learning. Sequences of examples also can promote transfer. Specifically, teachers need to design a sequence of examples that varies the superficial aspects of the examples, such as the setting or storyline. The variation of the superficial context forces students to pay attention to the underlying structural concepts common to all the examples (Butler et al. 2017).

Recommended reading. Perkins and Salomon (2012) offer a review and synthesis of current theories of transfer. They summarize the work on transfer into three stages: detect, elect, and connect.

Challenge 8: constraints of selective attention

Student example. During class, an instructor walks around the room and notices that many students are on social media or other Web sites not related to the class. When the instructor points this out, the students indicate that it is not a problem. They often multitask in class and also out of class when they study, and it doesn't interfere with their learning.

Description of the challenge. Attention is intentional, focused awareness of any external or internal stimulation. It is vital for learning. We learn very little unless we can focus and sustain attention on the learning tasks before us. Unfortunately, we have limited capacity and imperfect control of our attention. We are susceptible to distractions from extraneous sources, and we have difficulty sustaining attention over long periods of time. In addition, we cannot shift our attention instantaneously. We are apt to miss information during transitions when we engage or withdraw from a task (Gazzaley and Rosen 2016).

These constraints pose major challenges for learning. Whenever attention is split or divided between two or more sources of information, learning generally suffers. An especially prominent attention problem is media multitasking. Numerous studies have found that many students engage in nonacademic activities such as texting, social media, and scanning Web sites during class and while studying (McCoy 2016; Hora and Oleson 2017). Multitasking has a negative effect on the efficiency of learning, the quality of students' work, and is associated with lower grades (Glass and Kang 2019; Patterson 2017; Ravizza, Uitvlugt, and Fenn 2017; Fried 2008; Levitin 2014).

In addition to multitasking, teachers introduce distractions when their instruction is poorly organized or when they present extraneous information unrelated to the topic at hand. Poorly organized instruction can confuse students about where they should focus their attention. Some studies have shown that instructors' attempts to pique students' interest and capture their attention can backfire. When these episodes are unrelated or tangential to the material at hand, students may focus on the "seductive details" rather than relevant content (Rey 2012). The point is that many things can distract students, and a basic teaching challenge is to reduce distractions and help students manage their attention on the academic tasks at hand.

Recommendations. To help manage students' attention in class, teachers can adopt a policy to reduce distractions from media multitasking during class (May and Elder 2018). In addition, teachers can:

- help students become aware of how multitasking will make learning harder, not easier.
- take short breaks between topics during long classes.
- re-orient students to the topic and what they should focus on throughout the class.
- have only one, easily identified, point of focus at a time during class.
- identify any of their habits or tendencies that may contribute to distractions in class.

Recommended readings. Willingham (2010) explains the cognitive nature of multitasking in a short animated video. Gazzaley (2017) explores the neurological basis of attention in a one-hour lecture. Students often believe they are good at multitasking, and this mistaken belief is a major obstacle to effective studying (Chew 2014). Kuznekoff, Munz, and Titsworth (2015) examined the impact of texting and Twitter during lecture on student learning.

Challenge 9: constraints of mental effort and working memory

Student example. To understand the experience of poverty, students take part in an elaborate poverty simulation. Each student in a class is assigned a role with a certain income, assets and liabilities, home and family situation, and life history. The simulation takes place in rounds where the students have to make choices for themselves and work with others in response to some event. The students enjoy the simulation, but they learn little about poverty because it took all their effort and concentration to keep up with their assigned roles and all the rules and background information.

Description of the challenge. A major obstacle to learning is cognitive overload, which occurs when the demands of learning exceed the students' cognitive capacities and resources. When students are overwhelmed by information, they learn little. Overload is a common occurrence because we can process only a limited amount of information at one time, and information that is not processed adequately is quickly forgotten (Chandler and Sweller 1991).

A major source of cognitive load is the amount of new information presented during a class (Schwartz, Tsang, and Blair 2016a). Teachers speak at a rate much faster than students can write (Piolat, Olive, and Kellogg 2005). Studies indicate that students' lecture notes include less than half of the main ideas from a class period (King 1992; Kiewra 2002; Armbruster 2009). Faculty with years of advanced training often suffer from the *Curse of Expertise* (Hinds 1999). They no longer remember what it is like to be a novice learner. Thus, they underestimate the amount of time students need to learn a concept and overestimate the quality and completeness of their explanations.

Cognitive overload is triggered by two major limitations on learning in the human cognitive system. The first is a limitation of *mental effort*, which is part of attention. The second is the limited capacity of *working memory*, which can hold only a small quantity of new information.

Mental effort is a limited cognitive resource; there is always an upper bound on how well a person can concentrate. That boundary fluctuates depending on factors such as arousal or sleep deprivation, but there is always a limit. Cognitive load refers to the amount of mental effort a person must devote to a task to accomplish it. Some tasks have a low cognitive load, such as chatting with friends, and some are challenging, such as taking a major exam. People can distribute their mental effort across multiple tasks as long as the total cognitive load of all the tasks does not exceed their available mental effort. If the cognitive load exceeds the available mental effort, then performance degrades. For example, in good weather, a skilled driver can easily drive and chat with a passenger. In a heavy rainstorm, driving takes full concentration, and the driver will likely not want to chat with a passenger because it would take away mental effort from driving. Even a small reduction might affect driving performance.

Sweller and associates pioneered the study of cognitive load and its impact on learning in Cognitive Load Theory or CLT (Kirschner, Sweller, and Clark 2006; Paas, van Gog, and Sweller 2010; Sweller, van Merriënboer, and Paas 2019). Each student has a limited amount of mental effort. The cognitive load imposed by the concepts to be learned and the pedagogy used must be less than the students' available mental effort. If the cognitive load exceeds available mental effort, then the students will be overwhelmed and will not learn, even if the concept is within their ability to master.

Some concepts require a great deal, if not all, of available mental effort to master, such as understanding statistical significance testing (Paas, van Gog, and Sweller 2010). Different kinds of learning activities also contribute to cognitive load. When the presentation is fast-paced or disorganized, and when there are frequent distractions, cognitive load is higher (Schwartz, Tsang, and Blair 2016a). Finally, any distractions such as jokes, stories, asides, and clip arts on the part of the teacher that have nothing to do with learning relevant concepts also add to cognitive load. The total of all sources of cognitive load cannot exceed the available mental effort for each student, or the student will not learn. The challenge is to reduce or manage cognitive load to allow learning to occur (Clark, Nguyen, and Sweller 2006).

Working memory (WM) is a major constraint on learning because it has a limited capacity to hold information, about four chunks of information, and the duration is brief, about 15 seconds or less without rehearsal (Cowan 2010; Weinstein, Sumeracki, and Caviglioli 2019). Trying to process more than four chunks in WM will result in the rapid forgetting of at least some of the information. When students are studying a textbook, they often cannot remember the topic they read just a few minutes before. Furthermore, processing fewer than four chunks in WM does not ensure remembering.

Recommendations. Teachers have to balance the effectiveness of a teaching method or activity with the risk of overwhelming students with cognitive load. Clark, Nguyen, and Sweller (2006) outline a number of strategies for reducing cognitive load and making learning more efficient. For example, teachers should give students multiple opportunities to think about and apply concepts, both within a course and within a curriculum. The more often students use and apply information, the less cognitive load will be required to think about that concept, a process called automaticity. Teachers can solicit feedback from students to find out whether students are able to process the material adequately. For example, graduate students in a course on science teaching identified more than 30 ways to reduce unnecessary cognitive load related to lecture organization, slides and graphics, the instructor's projected notes, and the classroom atmosphere and pace (CWSEI 2015).

Teachers can improve coherence and reduce cognitive load by making the organization of their lectures explicit, building on prior knowledge, identifying connections among topics throughout the lecture, and segmenting the material into manageable and meaningful chunks. Kiewra (2002) found that students are better able to follow a lecture if they have a schematic outline with major headings, concepts, or questions to guide their notetaking.

Students expend a lot of effort trying to force information through the WM bottleneck into long-term memory. There are two ways of dealing with the WM bottleneck: chunking and dual coding.

WM capacity is measured in terms of chunks, which is information that is so highly organized and cohesive that it acts as a single unit in WM (Weinstein, Sumeracki, and Caviglioli 2019). Experts have bigger chunks of information than novices, which helps them get more information through WM and learn faster. It is the difference between memorizing a random string of letters, such as "P-T-M-A-O-P-I-H-O-S-U-P" and memorizing the same string of letters arranged to spell a familiar word, such as "H-I-P-P-O-P-O-T-A-M-U-S. Novices, such as students in introductory classes, have a hard time learning new information because they are unable to form large chunks. Teachers can help by presenting information in coherent chunks (Gobet 2005). Teachers can emphasize the overall relatedness of component concepts through concept maps or other diagrams. Teachers should try to avoid presenting information as a series of unrelated facts for students to master.

WM can hold two different kinds of information simultaneously: phonological or verbal information and visuospatial information such as diagrams and illustrations (Weinstein, Sumeracki, and Caviglioli 2019). People can hold more information in WM if some can be held verbally and some as images. Furthermore, presenting information in both verbal and visual modes increases learning, known as dual coding. Teachers can take advantage of dual coding in their presentations, presenting information in multiple modes. However, the different kinds of information have to be coordinated with each other to prevent extraneous cognitive load. Mayer (2014) has developed a theory of multimedia learning that can guide teachers in the design of effective presentations.

Recommended reading. There are abundant online sources of information about Cognitive Load Theory and its implications for education. Shibli and West (2018) provide an overview of how CLT is applied to the classroom. The Center for Education Statistics and Evaluation (CESE) in Australia has a set of free resources on CLT, including two monographs about CLT and its implications for teaching (CESE 2017, 2018). To learn more about Mayer's Theory of Multimedia Learning, see Mayer (2014). For a review of research relating to the effective design of presentation software slides, see Fisk (2019).

To learn more about WM and its implications for education, read the online booklet, *Understanding Working Memory: A Classroom Guide*, by Gathercole and Alloway (2007).

Putting the framework into practice

Implications of the cognitive framework

The cognitive framework has important implications for how we design, implement, and evaluate teaching. Fundamentally, it highlights the interaction among different aspects of the learning context. No single aspect stands alone in determining student learning. For example, greater prior knowledge reduces cognitive load, increases the likelihood of using effective learning strategies, reduces fear of learning, and enhances mindset. Ineffective learning strategies increase confidence without increasing learning, causing poor metacognition, and may make students less likely to overcome misconceptions or transfer accurate information. Furthermore, the contextual framework asserts that there is no single best teaching method across all situations. What works at a small liberal arts college may not work at an open-enrollment university. There will be semesters when a teaching method that usually works well does not work. There will be times when the learning activity that worked so well in the 8:00 am section falls flat in the 9:00 am section of the same course. For any teaching method, there are conditions under which it is less likely to be effective, regardless of how well-implemented (Fiorella and Mayer 2015; Yeager et al. 2019). For example, practice testing is effective in many circumstances but tends to be ineffective when students do not receive corrective feedback on their practice tests and when practice test questions and exam questions cover different material (Fiorella and Mayer 2015). The contextual framework does not, however, assert that all teaching methods are equal. We judge the effectiveness of pedagogy based on its robustness, i.e., its effectiveness across multiple contexts. For teachers, there are teaching methods with a higher likelihood of success in their teaching environment, but no pedagogy will work all the time.

The framework reveals the cognitive complexity of effective teaching. No teaching method can simply be implemented and assumed to be effective. Just because students have completed an activity or an assignment, we cannot assume they have learned what we intended. Any teaching method can be implemented badly and will not be effective. On the other hand, teachers with a deep understanding of how students learn are more likely to be successful in designing effective pedagogy across different contexts. To ensure that their pedagogy is effective, teachers should constantly assess student learning and make adjustments based on the feedback. They should have a ready collection of methods they can draw upon to address different cognitive challenges to replace or augment methods that are not proving effective. A teacher may teach two sections of the same course using the same textbook, syllabus, topic outline, and teaching materials, but to optimize learning, the teacher may have to teach the courses quite differently.

We note that this is a cognitive framework examining the challenges of various mental processes. It does not address social and emotional factors in learning, although these factors are implicit within several of the cognitive challenges, such as mindset and student fear and mistrust.

How to use this framework

The framework asserts that effective teaching is a matter of managing a nine-way dynamic interaction. Furthermore, several of these aspects, such as prior knowledge and cognitive load, are outside the direct control of teachers. Teachers need to monitor and manage all of the challenges and their interactions to bring about student learning. Teachers can use the cognitive framework in multiple ways.

Teachers can use the framework to adapt their teaching methods to their classroom context. Whatever teaching method teachers choose to use, they should consider each of the challenges because each one can affect student learning. Not surprisingly, some teaching practices are common across teaching approaches because they can address one or more of the cognitive challenges. For example, virtually all pedagogies make use of worked examples to help student learning (Chi et al. 1989). Within the framework, examples can be designed to enhance learning strategies, correct misconceptions, or promote transfer, depending on what is most needed by students. Feedback is another common feature among teaching methods. Feedback can be formulated to improve metacognition, build student trust, or promote a growth mindset, depending on what is most needed by students. Finally, formative assessment is another common element across teaching methods. Often faculty use formative assessment, like "clicker" questions, because intuitively it seems like a good idea. The framework helps teachers be more intentional in designing formative assessments to target specific cognitive challenges.

The framework shows that teaching for the first time is a daunting challenge for early career faculty. Despite the challenge, new faculty are often able to teach relatively well, based on their own academic experiences. The framework predicts an improvement of teaching skill with experience, and the framework can help with that development. The framework does argue for better preparation for teaching in graduate programs and ongoing professional development in teaching throughout the career.

When considering innovations such as a new educational technology, teachers can consider which components of the framework the technology will help address and if the technology is an improvement over current practice. The same holds true for trying new teaching methods such as problem-based learning or flipped classroom.

When problems arise during teaching, teachers can use the framework to diagnose and address obstacles to student learning. For example, if the problem is inadequate prior knowledge, the teacher might implement supplemental instruction. If the problem is poor metacognition, the teacher might use formative assessment to give students feedback about their level of understanding. However, if a teacher tries to help students by correcting their poor learning strategies and the problem is with misconceptions and prior knowledge, the approach will be unsuccessful.

The framework can be used in formative and summative evaluations of teaching. In self-evaluations, teachers can explain how they are addressing each component of the framework. For peer evaluations of teaching, the framework can help structure constructive feedback. Teachers can be evaluated on how well they meet each cognitive challenge and how well they adapt to the dynamics of the classroom.

Teachable moments

When all the challenges are successfully met, the result is optimal student learning—learning that is enduring and primed for generalization beyond the course. The goal of successful teaching is achieving optimal learning in as many students as possible, especially the ones who had little initial interest in the course. The concept of the *teachable moment* can help teachers navigate the cognitive framework to try to achieve optimal learning. We define a teachable moment as the point when optimal learning becomes possible in an individual student (Havighurst 1953). Below are the components of a teachable moment. The cognitive challenges that are addressed by each component are in parentheses. Teachable moments occur when students:

- Become aware of gaps or errors in their knowledge (Metacognition)
- See the value of correcting it (Mindset)
- Have a trusted source of accurate information (Student Fear and Mistrust)
- Believe they can master new understanding given sufficient effort (Mindset)
- Have sufficient mental resources to attend to that source (Selective Attention, Mental Effort)
- Have sufficient prior knowledge to comprehend information (Prior Knowledge)
- Recognize when they have mastered the new understanding (Metacognition)
- Rehearse new information for long-term recall (Learning Strategies)
- Prime new information to be recalled appropriately and be preferred over misconceptions (Misconceptions, Transfer)

Effective teaching brings about teachable moments for as many students as possible. Teaching skill involves knowing how to bring about teachable moments for a particular set of students, how to identify them when they occur, and how to make the most of them.

Can students still learn even if not all conditions for a teachable moment are met? The answer is yes. As noted before, some students are primed and motivated to learn and can achieve optimal learning with minimal support. Other students, however, can still learn, but that learning may be suboptimal. If they use ineffective study strategies, their learning may be transient. If they hold misconceptions, they may revert to the misconceptions after the course is over. If they fail to transfer their learning, they will not use what they have learned beyond the immediate course. If they lack sufficient prior knowledge to master course concepts, they may resort to rote memorization without understanding. If they have poor metacognition, they may blame the teacher for being devious and unfair, and failing to teach effectively. If they are overwhelmed by cognitive load, they may simply try to complete activities without gaining any knowledge. If they have fear and mistrust, they may seek the simplest way of passing the course and hope never to take another course in that topic or from that teacher again.

Concluding comments

In this article, we have proposed a research-based framework to guide development of effective teaching. The framework consists of nine cognitive challenges that have to be addressed for optimal student learning to occur. The proposed cognitive framework is contextual in nature, with each challenge influencing and being influenced by the others. The framework has important implications for the nature of teaching. Bain (2004), in his study of master teachers, described these implications:

> We must struggle with the meaning of learning within our discipline and how best to cultivate and recognize it. For that task, we don't need routine experts who know all the right procedures but adaptive ones who can apply fundamental principles to all the situations and students they are likely to encounter, recognizing when invention is both possible and necessary and that there is no single "best way" to teach. (174–75)

The framework does not promote a specific pedagogy or technology but outlines critical issues teachers need to consider regardless of the teaching approach. Teachers need to assess the state of each of the cognitive challenges and adapt pedagogy to address the current classroom context. The framework can help guide that adaptation. Teaching is a constant process of context-specific adaptation with the goal of bringing about optimal student learning.

Notes

1. For each challenge, first the cognitive process involved is described and then the situation where the cognitive process can undermine learning.
2. See pp. 152–68: http://teachpsych.org/ebooks/asle2014/index.php
3. See pp. 142–51: http://teachpsych.org/ebooks/asle2014/index.php
4. https://www.uwlax.edu/catl/guides/teaching-improvement-guide/how-can-i-improve/metacognition/
5. https://www.lifescied.org/doi/full/10.1187/cbe.12-03-0033
6. See pp. 7–19: http://teachpsych.org/ebooks/asle2014/index.php
7. See pp. 104–17: http://teachpsych.org/ebooks/asle2014/index.php
8. See pp. 293–98: http://teachpsych.org/ebooks/asle2014/index.php
9. See pp. 259–73: http://teachpsych.org/ebooks/asle2014/index.php
10. https://pdfs.semanticscholar.org/f991/c0cc11404a6ade236c93997958fb048ffc56.pdf
11. pdf.poojaagarwal.com/Pyc_Agarwal_Roediger_2014_APA.pdf#page=298
12. See pp. 131–41: http://teachpsych.org/ebooks/asle2014/index.php
13. See pp. 91–103: http://teachpsych.org/ebooks/asle2014/index.php

Disclosure statement

No potential conflict of interest was reported by the authors.

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References

Agarwal, P. K., and P. M. Bain. 2019. *Powerful teaching: Unleash the science of learning*. San Francisco: Jossey-Bass.

Agarwal, P. K., H. L. Roediger, M. A. McDaniel, and K. B. McDermott. 2018. How to use retrieval practice to improve learning. http://pdf.retrievalpractice.org/RetrievalPracticeGuide.pdf

Ambrose, S. A., M. Bridges, M. DiPietro, M. C. Lovett, and M. K. Norman. 2010. *How learning works: Seven research-based principles for smart teaching*. San Francisco: Jossey-Bass.

Ambrose, S. A., and M. C. Lovett. 2014. Prior knowledge is more than content: Skills and beliefs also impact learning. In *Applying science of learning in education: Infusing psychological science into the curriculum*, ed. V. A. Benassi, C. E. Overson, and C. M. Hakala, 7–19. Washington, DC: Society for the Teaching of Psychology. http://teachpsych.org/ebooks/asle2014/index.php.

Angelo and Cross. 1993. *Classroom assessment techniques*. San Francisco: Jossey-Bass.

Armbruster, B. 2009. Notetaking from lectures. In *Handbook of college reading and study strategy research*, 2nd ed., ed. R. F. Flippo and D. C. Caverly, 220–48. New York: Routledge.

Bain, K. 2004. *What the best college teachers do*. Cambridge, MA: Harvard University Press.

Ballen, C. J., C. Wieman, S. Salehi, J. B. Searle, and K. R. Zamudio. 2017. Enhancing diversity in undergraduate science: Self-efficacy drives performance gains with active learning. *CBE—Life Sciences Education* 16 (4): ar56. doi: 10.1187/cbe.16-12-0344.

Barkley, E. F., and C. H. Major. 2016. *Learning assessment techniques: A handbook for college faculty*. San Francisco: Jossey Bass.

Barnett, S. M., and S. J. Ceci. 2002. When and where do we apply what we learn? A taxonomy for far transfer. *Psychological Bulletin* 128 (4): 612–37. doi: 10.1037/0033-2909.128.4.612.

Benassi, V. A., C. E. Overson, and C. M. Hakala. 2014. *Applying science of learning in education: Infusing psychological science into the curriculum*. Washington, DC: Society for the Teaching of Psychology. http://teachpsych.org/ebooks/asle2014/index.php.

Bice, D., E. S. Curtis, W. Geerling, W. Goffe, A. Hoffer, S. Lindahl, M. Maier, B. Peterson, and W. Stock. 2014. Preconceptions of principles students. Mimeo. http://cook.rfe.org/Preconceptions_Bice_et_al_06_2014.pdf

Bjork, R. A., J. Dunlosky, and N. Kornell. 2013. Self-regulated learning: Beliefs, techniques, and illusions. *Annual Review of Psychology* 64 (2013): 417–44. https://pdfs.semanticscholar.org/4efb/146e5970ac3a23b7c45f-fe6c448e74111589.pdf. doi: 10.1146/annurev-psych-113011-143823.

Blasiman, R. N., J. Dunlosky, and R. A. Rawson. 2017. The what, how much, and when of study strategies: Comparing intended versus actual study behaviour. *Memory* 25 (6): 784–92. doi: 10.1080/09658211.2016.1221974.

Brady, S. T., B. M. Hard, and J. J. Gross. 2018. Reappraising test anxiety increases academic performance of first-year college students. *Journal of Educational Psychology* 110 (3): 395–406. doi: 10.1037/edu0000219.

Bransford, J. D., A. L. Brown, and R. R. Cocking, eds. 1999. *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.

Brod, G., M. Hasselhorn, and S. A. Bunge. 2018. When generating a prediction boosts learning: The element of surprise. *Learning and Instruction* 55 (June): 22–31. doi: 10.1016/j.learninstruc.2018.01.013.

Busom, I., C. Lopez-Mayan, and J. Panades. 2017. Students' persistent preconceptions and learning economic principles. *Journal of Economic Education* 48 (2): 74–92. doi: 10.1080/00220485.2017.1285735.

Butler, A. C., A. C. Black-Maier, N. D. Raley, and E. J. Marsh. 2017. Retrieving and applying knowledge to different examples promotes transfer of learning. *Journal of Experimental Applied Psychology* 23 (4): 433–46. doi: 10.1037/xap0000142.

Cahill, M. J., M. A. McDaniel, R. F. Frey, K. M. Hynes, M. Repice, J. Zhao, and R. Trousil. 2018. Understanding the relationship between student attitudes and student learning. *Physical Review Physics Education Research* 14 (1): 010107-1–010107-16.

Carl Wieman Science Education Initiative (CWSEI). 2015. Improving learning by reducing unnecessary mental load. Vancouver, Canada: University of British Columbia, CWSEI. http://www.cwsei.ubc.ca/resources/files/Cognitive-Load_CWSEI.pdf

Carpenter, S. K. 2014. Spacing and interleaving of study and practice. In *Applying science of learning in education: Infusing psychological science into the curriculum*, ed. V. A. Benassi, C. E. Overson, and C. M. Hakala, 131–41. Washington, DC: Society for the Teaching of Psychology. http://teachpsych.org/ebooks/asle2014/index.php.

Cavanagh, A. J., X. Chen, M. Bathgate, J. Frederick, D. I. Hanauer, and M. J. Graham. 2018. Trust, growth mindset, and student commitment to active learning in a college science course. *CBE—Life Sciences Education* 17 (1): ar10. doi: 10.1187/cbe.17-06-0107.

Centre for Education Statistics and Evaluation (CESE). 2017. *Cognitive load theory: Research that teachers really need to understand*. Sydney, New South Wales, Australia: CESE. https://www.cese.nsw.gov.au//images/stories/PDF/cognitive-load-theory-VR_AA3.pdf.

———. 2018. *Cognitive load theory in practice: Examples for the classroom*. Sydney, New South Wales, Australia: CESE. https://www.cese.nsw.gov.au//images/stories/PDF/Cognitive_load_theory_practice_guide_AA.pdf.

Cerbin, W. 2015. Metacognition. In *Teaching improvement guide.* La Crosse, WI: University of Wisconsin at La Crosse, Center for Advancing Teaching and Learning. https://www.uwlax.edu/catl/guides/teaching-improvement-guide/how-can-i-improve/metacognition/.

Chamberland, M., C. St-Onge, J. Setrakian, L. Lanthier, L. Bergeron, A. Bourget, S. Mamede, H. Schmidt, and R. Rikers. 2011. The influence of medical students' self-explanations on diagnostic performance. *Medical Education* 45 (7): 688–95. doi: 10.1111/j.1365-2923.2011.03933.x.

Chandler, P., and J. Sweller. 1991. Cognitive load theory and the format of instruction. *Cognition and Instruction* 8 (4): 293–332. doi: 10.1207/s1532690xci0804_2.

Chew, S. L. 2005. Seldom in doubt but often wrong: Addressing tenacious student misconceptions. In *Best practices for teaching introduction to psychology*, ed. D. S. Dunn and S. L. Chew, 211–23. Hillsdale, NJ: Lawrence Erlbaum Associates Publishers.

——— 2014. Helping students to get the most out of studying. In *Applying science of learning in education: Infusing psychological science into the curriculum*, ed. V. A. Benassi, C. E. Overson, and C. M. Hakala, 215–24. Washington, DC: Society for the Teaching of Psychology. http://teachpsych.org/ebooks/asle2014/index.php.

Chew, S. L., R. Bartlett, J. Dobbins, E. Y. Hammer, M. Kite, T. Loop, J. McIntyre, and K. A. Rose. 2009. Contextual approach to teaching: Bridging goals and outcomes. In *Undergraduate education in psychology: A blueprint for the future of the discipline*, ed. D. Halpern, 95–112. Washington, DC: American Psychological Association.

Chew, S. L., H. B. Beck, E. K. Houk, E. M. McLung, A. N. Wertenberger, E. A. Haine, M. G. Hardin, and E. C. Schneider. 2018. Trust in and rapport with the teacher as separate components of a successful student mindset. Paper presentation. Annual Conference on Teaching, Phoenix, AZ, October 2018.

Chew, S. L., H. S. Halonen, M. A. McCarthy, R. A. R. Gurung, M. J. Beers, R. McEntarffer, and R. E. Landrum. 2018. Practice what we teach: Improving teaching and learning in psychology. *Teaching of Psychology* 45 (3): 239–45. doi: 10.1177/0098628318779264.

Chi, M. T. H. 2013. Two kinds and four sub-types of misconceived knowledge, ways to change it and the learning outcomes. In *International handbook of research on conceptual change*, 2nd ed., ed. S. Vosniadou, 49–70. New York: Routledge Press.

Chi, M. T., M. Bassok, M. W. Lewis, P. Reimann, and R. Glaser. 1989. Self-explanations: How students study and use examples in learning to solve problems. *Cognitive Science* 13 (2): 145–82. doi: 10.1207/s15516709cog1302_1.

Chiu, J. L., and M. T. H. Chi. 2014. Supporting self-explanation in the classroom. In *Applying science of learning in education: Infusing psychological science into the curriculum*, ed. V. A. Benassi, C. E. Overson, and C. M. Hakala, 91–103. Washington, DC: Society for the Teaching of Psychology. https://teachpsych.org/ebooks/asle2014/index.php.

Clark, R., F. Nguyen, and J. Sweller. 2006. *Efficiency in learning: Evidence-based guidelines to manage cognitive load*. Hoboken, NJ: Pfeiffer.

Clement, J. 1982. Student preconceptions in introductory mechanics. *American Journal of Physics* 50 (1): 66–71. doi: 10.1119/1.12989.

Cowan, N. 2010. The magical mystery four: How is working memory capacity limited, and why? *Current Directions in Psychological Science* 19 (1): 51–57. doi: 10.1177/0963721409359277.

Cox, R. D. 2011. *The college fear factor: How students and professors misunderstand one another*. Cambridge, MA: Harvard University Press.

Daniel, D. B., and S. L. Chew. 2013. The tribalism of teaching and learning. *Teaching of Psychology* 40 (4): 363–67. doi: 10.1177/0098628313501034.

Daniel, D. B., and D. Poole. 2009. Learning for life: An ecological approach to pedagogical research. *Perspectives on Psychological Science: A Journal of the Association for Psychological Science* 4 (1): 91–96. doi: 10.1111/j.1745-6924.2009.01095.x.

Day, S., and R. Goldstone. 2012. The import of knowledge export: Connecting findings and theories of transfer of learning. *Educational Psychologist* 47 (3): 153–76. doi: 10.1080/00461520.2012.696438.

Dunlosky, J., and K. A. Rawson. 2015. Practice tests, spaced practice, and successive relearning: Tips for classroom use and for guiding students' learning. *Scholarship of Teaching and Learning in Psychology* 1 (1): 72–78. doi: 10.1037/stl0000024.

Dunlosky, J., K. A. Rawson, E. J. Marsh, M. J. Nathan, and D. T. Willingham. 2013. Improving students' learning with effective learning techniques: Promising directions from cognitive and educational psychology. *Psychological Science in the Public Interest: A Journal of the American Psychological Society* 14 (1): 4–58. doi: 10.1177/1529100612453266.

Ehrlinger, J., and E. A. Shain. 2014. How accuracy in students' self-perceptions relates to success in learning. In *Applying science of learning in education: Infusing psychological science into the curriculum*, ed. V. A. Benassi, C. E. Overson, and C. M. Hakala, 142–51. Washington, DC: Society for the Teaching of Psychology. http://teachpsych.org/ebooks/asle2014/index.php.

Engle, R. A., D. P. Lam, X. S. Meyer, and S. E. Nix. 2012. How does expansive framing promote transfer? Several proposed explanations and a research agenda for investigating them. *Educational Psychologist* 47 (3): 215–31. doi: 10.1080/00461520.2012.695678.

Farrington, C. A. 2013. *Academic mindsets as a critical component of deeper learning*. Chicago, IL: University of Chicago, Consortium on Chicago School Research. https://www.howyouthlearn.org/pdf/White_Paper_Academic_Mindsets_as_a_Critical_Component_of_Deeper_Learning_Camille_Farrington_April_20_2013.pdf.

Farrington, C., M. Roderick, E. Allensworth, J. Nagaoka, T. Keyes, D. Johnson, and N. Beechum. 2012. *Teaching adolescents to become learners. The role of noncognitive factors in shaping school performance: A critical literature review*. Chicago, IL: University of Chicago, Consortium on Chicago School Research. https://consortium.uchicago.edu/publications/teaching-adolescents-become-learners-role-noncognitive-factors-shaping-school.

Fiorella, L., and R. E. Mayer. 2015. *Learning as a generative activity: Eight learning strategies that promote understanding*. New York: Cambridge University Press.

Fisk, G. D. 2019. *Slides for students: The effective use of PowerPoint in education*. Athens, GA: University of Georgia Press.

Flavell, J. H. 1979. Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist* 34 (10): 906–11.

Fried, C. B. 2008. In-class laptop use and its effects on student learning. *Computers & Education* 50 (3): 906–14. doi: 10.1016/j.compedu.2006.09.006.

Fryberg, S. A., R. Covarrubias, and J. A. Burack. 2013. Cultural models of education and academic performance for Native American and European American students. *School Psychology International* 34 (4): 439–52. doi: 10.1177/0143034312446892.

Gathercole, S. E., and T. P. Alloway. 2007. *Understanding working memory: A classroom guide*. https://www.mrc-cbu.cam.ac.uk/wp-content/uploads/2013/01/WM-classroom-guide.pdf

Gazzaley, A. 2017. *The distracted mind—19th distinguished lecture on brain, learning and memory—Dr. Adam Gazzaley*. Video. https://youtu.be/b0YSb4D2F9w

Gazzaley, A., and L. D. Rosen. 2016. *The distracted mind: Ancient brains in a high-tech world*. Cambridge, MA: MIT Press.

Girash, J. 2014. Metacognition and instruction. In *Applying science of learning in education: Infusing psychological science into the curriculum*, ed. V. A. Benassi, C. E. Overson, and C. M. Hakala, 152–68. Washington, DC: Society for the Teaching of Psychology. http://teachpsych.org/ebooks/asle2014/index.php.

Glass, A. L., and M. Kang. 2019. Dividing attention in the classroom reduces exam performance. *Educational Psychology* 39 (3): 395–408. doi: 10.1080/01443410.2018.1489046.

Gobet, F. 2005. Chunking models of expertise: Implications for education. *Applied Cognitive Psychology* 19 (2): 183–204. doi: 10.1002/acp.1110.

Goffe, W. L. 2013. Initial misconceptions in macro principles classes. Mimeo. http://cook.rfe.org/Misconceptions.pdf

Grimaldi, P. J., and J. D. Karpicke. 2012. When and why do retrieval attempts enhance subsequent encoding? *Memory & Cognition* 40 (4): 505–13. doi: 10.3758/s13421-011-0174-0.

Guiffrida, D. A., and K. Z. Douthit. 2010. The Black student experience at predominantly White colleges: Implications for school and college counselors. *Journal of Counseling & Development* 88 (3): 311–318. doi: 10.1002/j.1556-6678.2010.tb00027.x.

Gulikers, J. T., T. J. Bastiaens, and P. A. Kirschner. 2004. A five-dimensional framework for authentic assessment. *Educational Technology Research and Development* 52 (3): 67–86. doi: 10.1007/BF02504676.

Hattie, J. 2009. *Visible learning: A synthesis of over 800 meta-analyses relating to achievement*. New York: Routledge.

Hattie, J., and H. Timperley. 2007. The power of feedback. *Review of Educational Research* 77 (1): 81–112. doi: 10.3102/003465430298487.

Havighurst, R. J. 1953. *Human development and education*. Harlow, UK: Longmans, Green and Co.

Hinds, P. J. 1999. The curse of expertise: The effects of expertise and debiasing methods on prediction of novice performance. *Journal of Experimental Psychology: Applied* 5 (2): 205–21. doi: 10.1037/1076-898X.5.2.205.

Hora, M. T., and A. K. Oleson. 2017. Examining study habits in undergraduate STEM courses from a situative perspective. *International Journal of STEM Education* 4 (1): ar1. doi: 10.1186/s40594-017-0055-6.

Howard-Jones, P. A. 2014. Neuroscience and education: Myths and messages. *Nature Reviews: Neuroscience* 15 (12): 817–24. doi: 10.1038/nrn3817.

Keeley, J. W., E. Ismail, and W. Buskist. 2016. Excellent teachers' perspectives on excellent teaching. *Teaching of Psychology* 43 (3): 175–179. doi: 10.1177/0098628316649307.

Khanna, M. K. 2015. Ungraded pop quizzes: Test enhanced learning without all the anxiety. *Teaching of Psychology* 42 (2): 174–178. doi: 10.1177/0098628315573144.
Kiewra, K. A. 2002. How classroom teachers can help students learn and teach them how to learn. *Theory into Practice* 41 (2): 71–80. doi: 10.1207/s15430421tip4102_3.
King, A. 1992. Comparison of self-questioning, summarizing, and notetaking-review as strategies for learning from lectures. *American Educational Research Journal* 29 (2): 303–23. doi: 10.3102/00028312029002303.
Kirschner, P. A., J. Sweller, and R. E. Clark. 2006. Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist* 41 (2): 75–86. doi: 10.1207/s15326985ep4102_1.
Kornell, N., and B. Finn. 2016. Self-regulated learning: An overview of theory and data. In *The Oxford handbook of metamemory*, ed. J. Dunlosky and S. K. Tauber, 325–40. New York: Oxford University Press.
Kuznekoff, J. H., S. Munz, and S. Titsworth. 2015. Mobile phones in the classroom: Examining the effects of texting, Twitter, and message content on student learning. *Communication Education* 64 (3): 344–65. doi: 10.1080/03634523.2015.1038727.
Levitin, D. J. 2014. *The organized mind: Thinking straight in the age of information overload*. New York: Dutton.
Lilienfeld, S. O. 2010. Confronting psychological misconceptions in the classroom: Challenges and rewards. *APS Observer* 23 (7): 36–39.
Lovett, M. C. 2013. Making exams worth more than the grade. In *Using reflection and metacognition to improve student learning: Across the disciplines, across the academy*, ed. M. Kaplan, N. Silver, D. LaVaque-Manty, and D. Meizlish, 18–48. Sterling, VA: Stylus.
Lyle, K. B., and N. A. Crawford. 2011. Retrieving essential material at the end of lecture improves performance on statistics exams. *Teaching of Psychology* 38 (2): 94–97. doi: 10.1177/0098628311401587.
May, K. E., and A. D. Elder. 2018. Efficient, helpful, or distracting? A literature review of media multitasking in relation to academic performance. *International Journal of Educational Technology in Higher Education* 15 (1): ar13. doi: 10.1186/s41239-018-0096-z.
Mayer, R. E. 2014. Research-based principles for designing multimedia instruction. In *Applying science of learning in education: Infusing psychological science into the curriculum*, ed. V. A. Benassi, C. E. Overson, and C. M. Hakala, 59–70. Washington, DC: Society for the Teaching of Psychology. http://teachpsych.org/ebooks/asle2014/index.php.
McCoy, B. 2016. Digital distractions in the classroom phase II: Student classroom use of digital devices for non-class purposes. *Journal of Media Education* 7 (1): 5–32. http://digitalcommons.unl.edu/journalismfacpub/90.
McDaniel, M. A., and A. C. Butler. 2011. A contextual framework for understanding when difficulties are desirable. In *Successful remembering and successful forgetting: A festschrift in honor of Robert A. Bjork*, ed. A. S. Benjamin, 175–98. New York: Psychology Press.
Morehead, K., M. G. Rhodes, and S. DeLozier. 2016. Instructor and student knowledge of study strategies. *Memory* 24 (2): 257–71. doi: 10.1080/09658211.2014.1001992.
Morris, C. D., J. D. Bransford, and J. J. Franks. 1977. Levels of processing versus transfer appropriate processing. *Journal of Verbal Learning & Verbal Behavior* 16 (5): 519–33. doi: 10.1016/S0022-5371(77)80016-9.
Murphy, P. K., and P. A. Alexander. 2013. Situating text, talk, and transfer in conceptual change. In *International handbook of research on conceptual change*, 2nd ed., ed. S. Vosniadou, chapter 31. New York: Routledge Press.
National Survey of Student Engagement (NSSE). 2016. *NSSE Annual Results 2016. Engagement insights: Survey findings on the quality of undergraduate education*. Bloomington, IN: NSSE. https://nsse.indiana.edu/research/annual-results/past-annual-results/nsse-annual-results-2016.html.
———. 2017. *NSSE Annual Results 2017. Engagement insights: Survey findings on the quality of undergraduate education*. Bloomington, IN: NSSE. https://nsse.indiana.edu/research/annual-results/past-annual-results/nsse-annual-results-2017.html.
Nguyen, N., and M. A. McDaniel. 2014. Potent techniques to improve learning from text. In *Applying science of learning in education: Infusing psychological science into the curriculum*, ed. V. A. Benassi, C. E. Overson, and C. M. Hakala, 104–17. Washington, DC: Society for the Teaching of Psychology. https://teachpsych.org/ebooks/asle2014/index.php.
Nicol, D. J., and D. Macfarlane. 2006. Formative assessment and self-regulated learning: A model and seven principles of good feedback practice. *Studies in Higher Education* 31 (2): 199–218. doi: 10.1080/03075070600572090.
Nuthall, G. 2007. *The hidden lives of learners*. Wellington, New Zealand: New Zealand Council for Education Research Press.
Paas, F., van Gog, T. T., and J. Sweller. 2010. Cognitive load theory: New conceptualizations, specifications, and integrated research perspectives. *Educational Psychology Review* 22 (2): 115–21. doi: 10.1007/s10648-010-9133-8.
Pashler, H., M. McDaniel, D. Rohrer, and R. Bjork. 2008. Learning styles: Concepts and evidence. *Psychological Science in the Public Interest* 9 (3): 105–19. doi: 10.1111/j.1539-6053.2009.01038.x.
Patterson, M. C. 2017. A naturalistic investigation of media multitasking while studying and the effects on exam performance. *Teaching of Psychology* 44 (1): 51–57. doi: 10.1177/0098628316677913.

Pérez, W., R. D. Cortés, K. Ramos, and H. Coronado. 2010. "Cursed and blessed": Examining the socioemotional and academic experiences of undocumented Latina and Latino college students. *New Directions for Student Services* 2010 (131): 35–51. doi: 10.1002/ss.366.

Perkins, D. N., and G. Salomon. 2012. Knowledge to go: A motivational and dispositional view of transfer. *Educational Psychologist* 47 (3): 248–58. doi: 10.1080/00461520.2012.693354.

Piolat, A., T. Olive, and R. T. Kellogg. 2005. Cognitive effort during note taking. *Applied Cognitive Psychology* 19 (3): 291–312. doi: 10.1002/acp.1086.

Pyc, M. A., P. K. Agarwal, and H. L. Roediger. 2014. Test enhanced learning. In *Applying science of learning in education: Infusing psychological science into the curriculum*, ed. V. A. Benassi, C. E. Overson, and C. M. Hakala, 78–90. Washington, DC: Society for the Teaching of Psychology. http://teachpsych.org/ebooks/asle2014/index.php.

Ravizza, S. M., M. G. Uitvlugt, and K. M. Fenn. 2017. Logged in and zoned out: How laptop internet use relates to classroom learning. *Psychological Science* 28 (2): 171–80. doi: 10.1177/0956797616677314.

Rawson, K. A., J. Dunlosky, and S. M. Sciartelli. 2013. The power of successive relearning: Improving performance on course exams and long-term retention. *Educational Psychology Review* 25 (4): 523–48. doi: 10.1007/s10648-013-9240-4.

Rey, G. D. 2012. A review of research and a meta-analysis of the seductive details effect. *Educational Research Review* 7 (3): 216–37. doi: 10.1016/j.edurev.2012.05.003.

Rosenshine, B. 2012. Principles of instruction: Research-based strategies that all teachers should know. *American Educator* 36 (1): 12–19. https://files.eric.ed.gov/fulltext/EJ971753.pdf.

Schneider, M., and F. Preckel. 2017. Variables associated with achievement in higher education: A systematic review of meta-analyses. *Psychological Bulletin* 143 (6): 565–600. doi: 10.1037/bul0000098.

Schwartz, D. L., J. M. Tsang, and K. P. Blair. 2016a. *The ABCs of how we learn: 26 scientifically proven approaches, how they work, and when to use them*. New York: Norton.

———. 2016b. Overcoming misconceptions and misplaced reasoning. In *The ABCs of how we learn: 26 scientifically proven approaches, how they work, and when to use them*, ed. D. L. Schwartz, J. M. Tsang, and K. P. Blair, 260–76. New York: Norton.

Shibli, D., and R. West. 2018. Cognitive load theory and its application in the classroom. *Impact* (issue 2). https://impact.chartered.college/article/shibli-cognitive-load-theory-classroom/

Son, J. Y., and M. J. Rivas. 2016. Designing clicker questions to stimulate transfer. *Scholarship of Teaching and Learning in Psychology* 2 (3): 193–207. doi: 10.1037/stl0000065.

Stephens, N. M., M. G. Hamedani, and M. Destin. 2014. Closing the social-class achievement gap: A difference-education intervention improves first-generation students' academic performance and all students' college transition. *Psychological Science* 25 (4): 943–53. doi: 10.1177/0956797613518349.

Stiegler-Balfour, J. J., V. A. Benassi, H. Tatsak, and A. Taatjes. 2014. The influence of guiding questions on skilled- and less-skilled readers' understanding of written discourse. In *Applying science of learning in education: Infusing psychological science into the curriculum*, ed. V. A. Benassi, C. E. Overson, and C. M. Hakala, 293–98. Washington, DC: Society for the Teaching of Psychology. http://teachpsych.org/ebooks/asle2014/index.php.

Sweller, J., J. J. G. van Merriënboer, and F. Paas. 2019. Cognitive architecture and instructional design: 20 years later. *Educational Psychology Review* 31 (2): 261–92. doi: 10.1007/s10648-019-09465-5.

Tanner, K. D. 2012. Promoting student metacognition. *CBE Life Sciences Education* 11 (2): 113–20. doi: 10.1187/cbe.12-03-0033.

Taylor, A., and P. Kowalski. 2014. Student misconceptions: Where do they come from and what can we do? In *Applying science of learning in education: Infusing psychological science into the curriculum*, ed. V. A. Benassi, C. E. Overson, and C. M. Hakala, 259–73. Washington, DC: Society for the Teaching of Psychology. https://teachpsych.org/ebooks/asle2014/index.php.

Veltre, M. T., K. W. Cho, and J. H. Neely. 2015. Transfer-appropriate processing in the testing effect. *Memory* 23 (8): 1229–37. doi: 10.1080/09658211.2014.970196.

Walton, G. M., G. L. Cohen, D. Cwir, and S. J. Spencer. 2012. Mere belonging: The power of social connections. *Journal of Personality and Social Psychology* 102 (3): 513–32. doi: 10.1037/a0025731.

Weinstein, Y., M. Sumeracki, and O. Caviglioli. 2019. *Understanding how we learn: A visual guide*. New York: Routledge.

Willingham, D. 2010. Multitasking.wmv. Video. https://youtu.be/34OZ-dsNkBw

Wilson, J. H., R. G. Ryan, and J. L. Pugh. 2010. Professor-student rapport scale predicts student outcomes. *Teaching of Psychology* 37 (4): 246–51. doi: 10.1080/00986283.2010.510976.

Winkelmes, M. A., M. Bernacki, J. Butler, M. Zochowski, J. Golanics, and K. Harriss Weavil. 2016. A teaching intervention that increases underserved college students' success. *Peer Review* 18 (12): 31–36. Washington, DC: Association of American Colleges & Universities. https://pdfs.semanticscholar.org/36ea/b10b05ba0b80ad43a86c3-b7af29e7972deaa.pdf.

Yeager, D. S., and C. S. Dweck. 2012. Mindsets that promote resilience: When students believe that personal characteristics can be developed. *Educational Psychologist* 47 (4): 302–14. doi: 10.1080/00461520.2012.722805.

Yeager, D. S., P. Hanselman, G. M. Walton, J. S. Murray, R. Crosnoe, C. Muller, E. Tipton, B. Schneider, C. S. Hulleman, C. P. Hinojosa, et al. 2019. A national experiment reveals where a growth mindset improves achievement. *Nature* 573 (7774): 364–69. doi: 10.1038/s41586-019-1466-y.

Yeager, D. S., V. Purdie-Vaughns, J. Garcia, N. Apfel, P. Brzustoski, A. Master, W. T. Hessert, M. E. Williams, and G. L. Cohen. 2014. Breaking the cycle of mistrust: Wise interventions to provide critical feedback across the racial divide. *Journal of Experimental Psychology: General* 143 (2): 804–24. doi: 10.1037/a0033906.

Yeager, D. S., C. Romero, D. Paunesku, C. S. Hulleman, B. Schneider, C. Hinojosa, H. Y. Lee, J. O'Brien, K. Flint, A. Roberts, et al. 2016. Using design thinking to improve psychological interventions: The case of the growth mindset during the transition to high school. *Journal of Educational Psychology* 108 (3): 374–91. doi: 10.1037/edu0000098.

Yin, Y.,. R. J. Shavelson, C. C. Ayala, M. A. Ruiz-Primo, P. R. Brandon, E. M. Furtak, M. K. Tomita, and D. B. Young. 2008. On the impact of formative assessment on student motivation, achievement, and conceptual change. *Applied Measurement in Education* 21 (4): 335–59. doi: 10.1080/08957340802347845.

Zimmerman, B. J. 2000. Self-efficacy: An essential motive to learn. *Contemporary Educational Psychology* 25 (1): 82–91. doi: 10.1006/ceps.1999.1016.