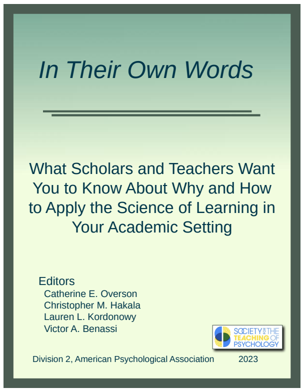

In Their Own Words

What Scholars and Teachers Want You to Know About Why and How to Apply the Science of Learning in Your Academic Setting

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Different Goals Imply Different Methods: A Guide to Adapting Instructional Methods to Your Context

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Overview

It would be great if effective methods for teaching worked in all contexts, irrespective of the nature of the content and student prior knowledge. It would be terrible if every context required a different, unpredictable, method for ideal learning. Learning research has shown us that the likely truth is somewhere between. Although the best choices for teaching methods do not work in all contexts, there are predictable features of contexts, and especially of learning goals, that can guide effective choices. This chapter provides such guidance so you can effectively select and adapt appropriate teaching methods for the particular learning goals you have in your instructional context.

A key message here is that debates about the best teaching methods can often be resolved by recognizing that different learning goals imply different kinds of knowledge, skills, and dispositions, which, in turn, suggest different ideal learning methods (cf., Metcalfe, this volume). Sometimes memorizing arbitrary facts is important, like the Earth is the third planet from the sun. Sometimes deep reflective understanding is important, like the reasoning behind scientific principles. These different goals, memorizing facts versus understanding general principles, imply different ideal teaching methods. There are other distinctions between learning goals, besides fact memorization and principle understanding, that are relevant to selecting effective methods. This chapter will present those distinctions and, for each kind of learning goal, suggest evidence-based teaching methods that have been demonstrated to be effective in rigorous experimental research on learning.

Our recommendations draw upon the Knowledge-Learning-Instruction Framework (Koedinger et al., 2012), which is called KLI (pronounced "klee") for short. The KLI framework is a consequence of a 10+ year effort involving a large group of researchers and educators to apply evidence-based teaching methods to new subject matter and to perform randomized controlled experiments within courses in math, science, and second language at the middle school, high school, and college levels. Sometimes these experiments produced the result predicted by prior studies, but not always. We were often surprised by cases where we did not get the predicted result. For example, instructors (ourselves included) tend to expect that presenting students with multiple visualizations of an idea (e.g., circle and bar representations of fractions) enhances their learning. However, research shows that this is not necessarily the case, as detailed below.

The development of KLI was not only driven by these experiments, but also by theories of learning both from cognitive science and from the Artificial Intelligence area of machine learning. Just as we saw a great variety of learning goals and teaching methods, the literature also reveals a great variety of learning theories, including theories of memory, of pattern learning, of skill acquisition, of information comprehension, and of sense making. In short, human learning is highly varied and richly complex.

KLI Helps Categorize Learning Goals and Direct Selection of Appropriate Instructional Methods

A key observation of KLI is that different learning processes are needed for different learning goals. For some learning goals, verbatim (or literal) recall is needed, for example, to memorize foreign language vocabulary, that “k” makes the ka sound, the value of constants in science or math, and the date of an important event. For some learning goals, learning situational patterns and appropriate responses to those patterns are needed, for example, to acquire skills in reading or writing (e.g., knowing when to add “ies” to pluralize a noun) and in math or science (e.g., recognizing which two formulas to apply to find the area of an irregular shape made up of two regular shapes). For some learning goals, reflecting and making sense of a situation is critical. Making sense is important in evaluating the merits of an argument, in understanding how molecular structure constrains a chemical reaction, and in analyzing the motivations of Shakespeare’s Hamlet.

Different learning processes are needed for memory of a verbatim fact, for generalizing or inducing a pattern or skill, and for making sense of a general principle. In each case, different instructional methods are ideal to achieve that goal. As we discuss dependencies between learning goals and different methods of teaching, we will provide examples of results from experimental research studies showing both when a particular method works well and when it does not (i.e., its opposite method may work better).

What Are Important Distinctions Between Goals?

You can distinguish learning goals based on the nature and complexity of the knowledge to be learned. The KLI Components of knowledge involve a retrieval condition, which can be either a single item (“constant”) or a general pattern (“variable”) and a response, which can also be either a single element or a general pattern. Knowledge can be in a verbal or a non-verbal form (e.g., something one can do that they cannot directly express). Some knowledge is arbitrary, a matter of design or convention, and some knowledge has a rationale.

Facts to Remember

The KLI framework uses the term “fact” to refer to relatively simple types of knowledge that express an arbitrary or conventional association between two particular items, like a word and its definition, a historical event and the date it occurred, or a foreign language word and its English translation. Learning facts, in the KLI sense, involves only verbatim memory—there is no need for nuanced generalization and no opportunity for understanding because the association is a matter of convention (e.g., the French picked “amour” whereas the English picked “love” to express the same idea).

In KLI, facts are types of knowledge where the retrieval condition is one item (e.g., English for amour) and the response is one item (e.g., love). Note that this technical use of “fact” differs somewhat from everyday use. People sometimes use the term “fact” to describe a piece of information that is uncontestable. However, although some uncontestable pieces of information are indeed facts (e.g., π is the symbol chosen to represent the ratio of a circle’s circumference to its diameter), other “facts” are actually principles (e.g., Newton’s first law) in the KLI sense. Thus, in KLI, a fact is more narrowly defined—it is indeed something that is true, but merely by convention (e.g., Саша in Russian is pronounced "Sasha" in English). In contrast, a "principle" in the KLI sense is not arbitrary; it can be rederived or rediscovered.

Students learn facts through memory processes. Memory-based learning is improved through repetition, spaced exposure or practice, and active retrieval practice (Anderson & Lebiere, 1998; Logan, 1988). Facts cannot be induced based on generalizations: many examples of German words for different berries do not produce a pattern that yields an unknown translation. Additionally, KLI facts cannot be understood based on principled reasoning: there is no derivation for why π is the symbol for the ratio of a circle's circumference to its diameter. As we move on to more complex forms of knowledge, it is worth noting that all forms of acquired knowledge are subject to forgetting and will fade without use. Thus, memory-enhancing instructional methods, like repetition, spacing, and practice, remain relevant even if other methods are more distinctly effective.

Skills to Generalize

Skills are more complex than facts because they are adaptable. We define skills as types of knowledge where a variety of retrieval conditions can be mapped to a variety of responses (cf., Gentner et al., 2009), while this mapping is nonverbal in nature (Alibali & Koedinger, 1999; Dienes & Perner, 1999). For example, the skill of finding the area of triangle can be applied in a variety of conditions (i.e., the triangle can have a different sized base or height), and the response varies accordingly (i.e., the computed area depends on the particular base and height). Competence in this skill does not guarantee that it can be fully and accurately explained in words, especially nuances of condition. Try expressing precisely how to identify the base and height of a triangle or all the ways you choose to use the article "the" instead of "a". Certainly, many motor skills are not easily expressed in words and, in fact, experts who attempt to express them are sometimes wrong (e.g., some expert tennis players indicate flipping their wrist imposes top spin when it is actually the upward motion of the racket). Skills, however, are much more ubiquitous—everything you *learn to do* is based on skill acquisition: reading, writing, problem solving, composing, analyzing, designing, inventing, and interacting. Many skills are learned outside of conscious awareness, such as skills of social interaction (e.g., nods, gestures, and facial expressions) that can indicate attentiveness, confusion, a desire to move on or to say something, etc. Skill acquisition requires accurate generalization from one situation to another (Anderson & Lebiere, 1998). For example, an expert reader has acquired skills to comprehend text with words used in combinations they have never seen before.

Students learn skills by observing and practicing them. For example, young children get an immense amount of practice in forming plural nouns by listening to and producing them in speech. Tennis players practice hitting balls in a variety of situations when they play. Practice situations generally offer feedback; for example, turn-taking in social interactions offers feedback by either being successful or resulting in a social error (e.g., unintentionally interrupting another person).

Principles to Understand

Principles are yet more complex than skills (Koedinger et al., 2012). KLI principles are defined as types of knowledge where, like skills but unlike facts, a variety of retrieval conditions can be mapped to a variety of responses (Gentner et al., 2009), where, unlike facts, the mapping has rationale and, unlike skills, this mapping is verbal in nature (Alibali & Koedinger, 1999; Dienes & Perner, 1999). That is, principles are similar to skills in the sense that they are adaptable. For example, there are many ways to explain how global warming results in rising sea levels. However, there is a rationale that links the retrieval condition and the response that can be explained. For example, the rationale linking global warming and rising sea levels is that land-based polar ice caps melt, adding more water in the oceans.

Like skills, well-acquired principles generalize across situations (Anderson et al., 1995; Li et al., 2015). For example, a student who has understood the relation between melting ice caps and rising sea levels might wonder whether the level of liquid water in a glass with ice will go up when the ice melts.

One way students learn principles is through explanations (Asterhan & Schwarz, 2009; Chi et al., 1989; Graesser et al., 2005). Students may construct explanations themselves; for example, they may read a sentence stating that global warming causes rising sea levels and may wonder why, which may cause them to come up with an explanation by drawing on what they already know about the issue. Students can learn from "self-explaining" even without saying it out loud (see Chi & Boucher, this volume). Students can get further benefits from being asked to state or write an explanation, whereby a teacher can provide feedback. It is often important to give students feedback on their explanations so they are more accountable to engaging in sense-making and can refine the scope and accuracy of their understanding (cf., Aleven et al., 2001).

Which Teaching Methods Are Best for Each Kind of Learning Goal?

There are many different ways to teach and, more generally, to support student learning. Teaching is obviously not just about providing clear instructions or explanations. Teaching is also about structuring activities, including selecting content for those activities, prompting students to perform actions (e.g., write, solve, etc.), and providing feedback to students on those actions. Many questions arise: When should students read versus practice? How much reading and how much practice? Should content and practice be repeated, and if so, how often and when? Should content and practice on a single topic be provided all at once or intermixed with content and practice on other topics? Should you have students read rules or study examples? Should you provide the explanations for the steps in examples or ask students to generate those explanations? This *book* is about answers to these questions. This *chapter* is particularly about when the answer to these questions changes depending on the context, including content you are teaching and the prior knowledge of students (cf. Metcalfe, this volume).

Methods for Supporting Long-term Retention of Facts

School is much more than learning and retaining arbitrary facts or associations. At the same time, often learning facts is important. Fast and easy retrieval of core facts is often crucial for future learning. Fluent learning of the fact (as per KLI) that the letter "s" makes the sound "es", is critical to future learning from reading. Fluent learning of 3+4=7 and other math facts is critical to future learning of multi-digit arithmetic procedures, like how to add 53+84. Beyond importance of learning some facts, probing what teaching methods best support fluent fact learning also provides us with a good contrast for exploring how different methods best support more complex skill and principle learning, as we discuss in the next sections.

One of the most powerful teaching methods for learning facts is retrieval practice, sometimes called "testing" (e.g., Roediger & Karpicke, 2006a&b; Yang et al., this volume). The core idea is that repeated practice retrieving (e.g., recalling the sum of 3+4, of 5+3, etc.) yields better learning outcomes than repeated study (e.g., reading through 3+4=7, 5+3=8, etc.).

There are other instructional methods that are particularly effective for supporting student learning of facts, particularly students' long-term retention of and fluency with them. One simple method for supporting long-term retention of facts is for students to get repeated practice. Most facts are not learned with just a few practice opportunities, but require many opportunities, like 10 or more, and even more to get from accurate to fast and fluent performance (cf., Dunlosky et al., this volume). Another method important for learning facts is spaced practice (e.g., Pavlik & Anderson, 2005; Rohrer & Hartwig, this volume). Repetition and spacing are also worthwhile for learning skills and principles—

skills and principles need to be remembered and applied. However, as we will see later, more practice instead of studying examples, while best for learning facts, is not always best for learning more general problem-solving skills.

To better understand what teaching methods work best for facts, it is helpful to contrast methods that do not aid learning of facts. Consider the multimedia principle (e.g., Clark & Mayer, 2016; Mayer, this volume), which states that having students read and study text that includes relevant images or diagrams often produces better learning than having students read the text alone. Below we discuss effective uses of the multimedia principle for learning principles, but this method does not improve memory of arbitrary facts. For example, in one study (Mayer, 1989), students given text with illustrations (e.g., about hydraulic drum brakes) were no better or somewhat worse at memorizing arbitrary facts (e.g., "drum brakes consist of a cast-iron drum") than students just given the text (e.g., 41% vs. 43% correct in recognizing verbatim text). As we discuss later, students given illustrations were better at answering transfer questions (e.g., "Why do brakes get hot?"). But when it comes to fact memory, as the Mayer (1989) study indicates, adding illustrations "should not help in verbatim retention of factual material" (p. 243).

Methods for Supporting General Skill Learning and Transfer

Skill learning is ubiquitous in academic learning, including decoding skills in reading, math skills for problem solving, scientific skills for reasoning from data, interpretation skills for extracting meaning from a story or historical event, writing skills for expressing ideas in compelling and clear terms, social communication skills for empathetic listening, and contributing new ideas that build on others, etc. Much of this skill learning happens implicitly through practice; arguably, some of the most powerful methods for supporting skill learning are summarized in the notion of deliberate practice (Ericsson et al., 1993). Key features of deliberate practice include: 1. learners are given well-designed practice tasks at the edge of their competence, 2. they get timely feedback on their performance on these tasks, 3. they get multiple repeated opportunities to move toward more accurate, desired performance, and 4. tasks are varied strategically to foster accurate generalizations that facilitate transfer of learning of these skills into new contexts.

Each of these four factors has been further elaborated. For example, research on feedback (2 above) suggests that high quality timely feedback a) highlights errors and avenues for improvement, b) illustrates, when needed, correct or desired performance, and c) provides explanations for why such performance is correct or desirable.

Together, these deliberate practice recommendations have much in common with the recommendations for retrieval practice, which are powerful for enhancing memory of verbatim facts. However, there are both additional and contradictory recommendations that emerge when the learning goal is general skill learning rather than when it is verbatim fact memory. These differing recommendations emerge from the nature of skills needed to apply *generally* but accurately (i.e., not over-generally) across a variety of different conditions. Thus, varied task presentation (4 above) and explanatory feedback (c above) are additional recommendations that aid generalized skill learning but may slow down verbatim fact learning. For skill learning, one not only needs verbatim *retrieval practice* but also *generalization practice* in varied contexts.

Perhaps more important, there are situations in skill learning in which an exclusive focus on retrieval practice can be counterproductive. Evidence on learning algebra equation solving (Kalyuga et al., 2003), for example, indicates that novice learners learn better when about half of the retrieval and generalization practice problems are replaced with worked example solutions (already solved problems). Multiple studies on this worked-example effect (see Recommendation 2 in Pashler et al., 2007; see also Renkl, this volume) demonstrate that passive study of worked examples prepares students for generalization practice, facilitating more accurate initiation for student induction of skills and yielding less overwhelming cognitive load than when novice students engage too soon in practice problems. Benefits of worked examples for skill learning can be further enhanced by prompting students to “self-explain”, that is, to provide their own explanations for the decisions/steps illustrated in worked examples (see Recommendation 7 in Pasher et al., 2007). This self-explanation prompting method is particularly powerful for procedural skills that convert general principles (covered next) into action.

Methods for Supporting Learning and Understanding of Principles

Some students explain principles spontaneously. However, research shows that many students do not spontaneously engage in explanation processes (Ainsworth et al., 2002). Hence, instructional interventions that support learning of principles often seek to engage students actively in explanations (Chi, 2009). For example, before reading a textbook passage, a teacher may tell students to underline causal claims and explain these to themselves. An online learning platform may show a message that asks students to think about examples from their own experiences while watching a video. A workbook may offer fill-in-the-blank sentences for students to complete to construct an explanation. Such self-explanation prompts have proven effective in multiple instructional contexts (Aleven & Koedinger, 2002; Chi et al., 1994; Renkl et al., 1998).

Generally, the goal is to engage students actively in the explanation process (Chi, 2009). A multitude of methods can achieve this goal; for example, collaboration (Hausmann et al., 2004; Teasley, 1995), teacher-led classroom discussions, peer tutoring, or computer-based tutoring. When students collaborate, they may disagree on how to explain a principle, which may prompt them to discuss their view and agree on a jointly constructed explanation (Schwartz, 1995). Teacher-led classroom discussions can function the same way. For example, a teacher prompts students to construct explanations themselves and then invites or provides challenges to their initial ideas (Cobb, 1995). One-on-one tutoring may involve prompts for explanations (Grasser et al., 2001). Computer-based tutors can prompt students to input explanations via text or menu-based entry followed by feedback that drives further thinking (Aleven & Koedinger, 2002; Johnson & Mayer, 2010; van der Meij & de Jong, 2011). Finally, the methods mentioned above for supporting learning facts or skills can be helpful for learning principles as well (Koedinger et al., 2012).

Practice-Based Advice in Applying KLI

This section provides practice-based advice on using the KLI framework in making decisions about teaching or designing instruction. It does so in the form of scenarios where you are asked to think through what you would do and why, and to compare your predictions and explanations with actual research results and theory. Consistent with KLI, we especially highlight how the same instructional method may work well for some learning goals but not for others.

Science Text Recall Scenario

***Goals and Assessment*.** In this scenario, the learning goal for undergraduate students is to enhance memory of written passages on scientific topics like “The Sun” and “Sea Otters”. These passages involved about 300 words. Students’ memory of the passage was tested by prompting them with the name of the passage and counting how many of the 30 key ideas in the passage they were able to generate in free recall (allowing for some variation in expression of a key idea).

Instructional Method and Your Prediction. To determine which instructional method better helps students’ textual memory, two methods were investigated. The first method uses retrieval practice where students study (S) the passage once, then are tested (T) three times by asking them to recall the text (STTT). The second method involves repeated study of the prose (SSSS). In both cases, no feedback was provided.

What instructional method (practice testing or repeated study) do you predict will better help text memory, in the short term (5 minutes later) and longer term (1 week later)? *Try to answer yourself before reading on!*

Observe Results and Explain**.** Roediger and Karpicke (2006a) conducted such an experiment and found that students who practiced testing (STTT) did better on a 1-week delayed post-test than the students given the method emphasizing study (SSSS), 61% vs. 40% on average, respectively. Interestingly, the study group (SSSS) did better on the immediate post-test (5 minutes later), recalling 83% of the ideas on average, than the testing group (STTT), who recalled 71% of the ideas.

What is the theory behind why these results were observed? How can you explain these results? *Try to answer yourself before reading on!*

Theoretical Explanation. Applying the KLI framework, we first note that the learning goal involves memory of facts, that is, memory for the ideas expressed in the text. While verbatim recall of these ideas was not required, students were asked to list only the ideas present in the text. They were not asked questions requiring any generalization of the ideas, like making inferences about sea otter behavior in a context that was not described in the text. The learning goal was to learn specific facts, not general skills or principles. Memory is the key learning process for facts, neither induction nor understanding are required. Memory is enhanced by repetition, spacing, feedback, and testing (i.e., retrieval practice). The better long-term results for the testing group are a consequence of retrieval practice, neither feedback nor spacing were provided. Memory is enhanced by testing for various reasons. The instructional activity (recall) matches the test activity (recall)—one learns best what one does. Retrieval practice may also provide learners with opportunities to create multiple paths for retrieval.

What about the immediate test results? Because there was no feedback on the test practice, the test group had only one exposure to the passage (the first and only S) whereas the study group had the initial exposure plus three repetitions (the four S's). With this extra repetition, the study group initially learned more, reaching 83% rather than 71% correctness on the immediate test. Interestingly, students thought they learned more from the study group, as evidenced by higher predictions than the test group that they would remember 1 week later. This result is consistent with the KLI notion that we cannot directly observe our own learning processes.

What if feedback had been provided? Then the test group would have had equivalent opportunities for exposure to the content and they would also have tended to perform better than the study group, even on the immediate test.

Boundary Conditions**.** If you want students to feel or perform better right after instruction on facts, then repeated study is better than practice without feedback. However, in the longer-term, practice, especially with feedback, yields better retention outcomes. When the learning goal is skills, especially skills involved in multi-step problem solving, then retrieval practice after one opportunity to study text and an example is not ideal. Instead, novice students learn complex skills better (e.g., Sweller & Cooper, 1985) when they do just as much example study as they test themselves in problem solving practice (STST). More practice is needed to achieve expertise in skills, and the benefit of worked examples reverses as students get closer to expertise (e.g., Kalyuga et al., 2003).

Geometry Problem Solving, Explanation, and Transfer Scenarios

Geometry Scenario 1

***Goals and Assessment*.** In a geometry class, the learning goals were for students to apply and understand properties of angles, such as in the context of parallel lines, perpendicular lines, and/or triangles. Three types of learning were assessed. To assess student learning of applying properties in problem solving, students were given problems with geometric figures labeled with some properties and/or angle values. For example, one problem asks: given triangle ABC with two equal sides (AB = BC), and a value for one base angle, <A = 30, what are the values of the other angles? (Answer: <B=30, <C=120.) To assess understanding, students were asked to explain their steps. For example, why is <B=30? (Answer: Because the base angles of an isosceles triangle are equal.) In a second assessment of understanding, students were given novel "not-enough-information" problems where they were instructed to decide whether or not they could solve a problem. For example, given triangle ABC, and a value for one base angle, <A = 30, do you have enough information to find the values of the other angles? (Answer: No, there is not enough information.)

***Instructional Method and Your Prediction*.** Toward achieving these learning goals, students received practice with an intelligent tutor system. They were randomly assigned to one of two versions of the system that used different instructional methods. In version A, students were tutored with as-needed feedback, hints, and adaptive problem selection on problems like the application assessment question above. In version B, students were tutored on the same kinds of problems, *but they were also* asked to explain each of their steps by typing in or selecting the relevant geometry principle. They received as-needed feedback and hints on their explanations as well as their problem-solving steps. Students using version B spent more time on average than students using version A (7.3 hours vs. 6.1 hours). *Based on the results of the three kinds of assessments above, which instructional method, A or B, leads to better student learning?* Consider whether results may be different for the problem-solving application test versus one of the tests of understanding.

***Observe Results and Explain*.** Researchers (study 1 in Aleven & Koedinger, 2002) found that students who practiced giving explanations (version B), learned more as demonstrated by better performance on all three tests (statistically reliable in all cases) compared to students in version A who did not provide explanations. Student average post-test scores in version A versus version B were 49% vs. 68% for the problem-solving test, 30% vs. 57% for the explanation test, and 24% vs. 55% for the not-enough-information transfer test. *Why did students in version B learn more?*

Theoretical Explanation. Were you tempted to consider reasons why having students provide explanations would enhance their learning? Providing explanations may have enhanced learning, but another possibility is that students learned more from version B because they had more opportunities to practice. The next scenario resolves this uncertainty.

Geometry Scenario 2

Prediction. Now, imagine we give students the same amount of time in the two groups, but otherwise keep the instruction and assessments the same. This means that students with version B, doing explanation as well as problem solving, will likely not be able to practice solving as many problems as students in version A, who are only problem solving. *Based on the results of the three kinds of assessments, which instructional method, problem solving only (A) or problem solving and self-explanation (B), leads to better student learning?*

Observe Results and Explain. This experiment was study 2 in Aleven & Koedinger (2002). With instruction time the same for the two versions, indeed, the students providing explanations in version B practiced half as many problems (83) as students using version A (166 problems). Not surprisingly, version B students learned how to provide better explanations than those in version A (52% vs. 42%). It may be more of a surprise that, despite getting half as much practice, version B students performed just as well as version A students on the problem-solving post-test (60% vs. 59%). Most important, the self-explainers (version B) performed significantly better than the pure problem solvers (A) on the not-enough-information transfer test (59% vs. 41%). *Why did students in method B learn to better explain and transfer their knowledge while learning problem-solving just as well (but not better)?*

***Theoretical Explanation**.* Key to explaining these results is the KLI distinction between skills, sometimes called procedural knowledge (Anderson et al., 1995), and principles, sometimes called declarative knowledge (Aleven & Koedinger, 2002) or conceptual knowledge (Rittle-Johnson et al., 2001). Self-explanation supports conceptual learning of the geometry principles and, quite sensibly, practice explaining produces better outcomes on the explanation assessment. Because principle knowledge is verbal, it is accessible for reflection—thus, the self-explainers are better able to resist temptation in the not-enough-information transfer assessment. They can access the verbal explanation (e.g., “base angles of an isosceles triangle are equal”) and reflect (e.g., “I don’t have enough information because I do not know if the triangle has two equal sides”). Because skill knowledge is acquired through doing practice tasks with feedback, the problem-solvers (version A) develop better skill knowledge. Yet, they do no better on the problem-solving post-test. Why is that? The principle knowledge can also be used, though more slowly and deliberately, in problem solving. So, the ground self-explainers lost through less repeated practice toward learning skills, they gained through more opportunities to learn principles through interactive explanation.

***Boundary Conditions*.** It is important to note that self-explanation is not always an effective instructional method. Verbatim memory of a face (a kind of fact in KLI) is actually harmed by instructions to verbalize (or explain) what you saw (Schooler et al., 1997). Second-language learning of accurate selection of the proper English article to precede a noun phrase (e.g., in this sentence, “a” before “noun phrase”, “the” before “proper English article”, and nothing before “accurate selection”) is an interesting case. At least for first language learners, this is non-verbal skill knowledge in KLI, and most of the rules are arbitrary (e.g., “the Pacific Ocean” but not “the Lake Michigan”). This knowledge is in the skill category, not in the principle category, in KLI. Thus, KLI predicts self-explanation will not help. Indeed, for this learning goal (picking the right article), multiple learning experiments (Wylie, 2011) demonstrated no enhanced learning by inserting self-explanation activities in place of practice.

Fraction Representations and Explanation Scenarios

Fractions Scenario 1

***Goals and Assessment*.** Imagine you are an elementary school math teacher teaching students about fractions. Your textbook uses number lines, pie charts, and sets to illustrate various fraction scenarios. You want students to understand that equivalent fractions have the same magnitude.

Instructional Method and Your Prediction. You create tasks with various representations where students have to draw a representation of an equivalent fraction and decide whether the magnitude has changed. You only have one class period available for this exercise, so you wonder whether it is necessary to prompt students to self-explain why the magnitude remains the same (version A), as doing so will take time. Alternatively, you consider skipping the self-explanation prompts to provide additional repeated practice opportunities (version B). *Which instructional method, A or B, will lead to better learning (as assessed by a delayed post-test given six days after instruction)?*

Observe Results and Explain**.** Rau and colleagues (2015) compared these two conditions in an experiment on fractions learning and found that self-explanation prompts led to higher learning gains. Students with version A scored 2.4 out of 3 whereas those with version B scored 1.42 out of 3. *How might you explain this result?*

Researcher Explanation. Rau and colleagues (2015) reasoned that, without self-explanation problems, students were unable to integrate the different representations into one picture and mental model about fractions, leading to confusion. With self-explanation, students may have been able to understand the complementary viewpoints of fractions depicted by the different visual representations.

Fractions Scenario 2

Instructional Method and Your Prediction**.** Regarding the same fractions lesson, you might now wonder: would it not be better to use only one representation (e.g., only pie charts), so that students are not confused about how fractions can be represented in so many different ways? Will practicing and explaining with one representation (version C) yield better learning than practicing and explaining with multiple representations (version A)?

Observe Results and Explain**.** Rau and colleagues' (2015) found that multiple representations with self-explanation prompts (version A) were more effective than a single representation with self-explanation prompts (version C): students with version C scored 1.97 out of 3 compared to 2.4 out of 3 for version A. *How might you explain this result?*

Researcher Explanation*.* Rau and colleagues (2015) reasoned that it is good for students to be exposed to multiple representations that highlight complementary fraction subcontracts (e.g., fractions as parts of a whole or fractions as parts of a length), but only if students are prompted to self-explain how the different representations depict information about fractions. Without prompts to self-explain, students are unlikely to spontaneously reflect on the different fraction interpretations. Therefore, the potential benefit of multiple representations is only realized when combined with self-explanation prompts.

Altogether, these findings illustrate the importance of including supports that engage students actively in explanation processes when the goal is to understand complex principles, such as how various representations depict fractions.

Conclusion

We hope this chapter supports you in making good selective decisions from the very rich and growing literature on how people learn and how to enhance student learning. It is important to consider the learning goal you want your students to achieve: Does it involve facts that need to be memorized, skills that need to be generalized, or principles that need to be understood? Given your goal, select associated methods like retrieval practice and spacing to support fact memory, worked examples and varied repeated practice with feedback to support skill generalization, self-explanation, and classroom dialogue to support principle understanding. Refer to Koedinger et al. (2013) for 30 methods specifically associated with memory, generalization, or understanding support. Finally, we hope that by prompting you to explain why and when different methods work and do not work, you are now better able to select and adapt methods based on your and your students' needs.

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