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Introduction

Improving student learning in low-maintenance and cost-effective ways

The need to improve educational achievement is greater now than ever before. An increasingly globalized and competitive workforce demands that students meet higher and higher expectations for mastery of content and skills. Due in part to concerns over the apparent failure of the education system to meet these standards, recent decades have witnessed a number of changes to educational practices that are designed to enhance student achievement. However, curricular changes that emphasize accountability, standardized testing, teacher evaluations, and educational technology have yet to produce sizeable achievement gains commensurate with the time, effort, and funding that have been required to implement them.

An approach to improving education that is often overlooked is the application of evidence-based techniques that are known to enhance learning. Over 100 years of research on human cognition has led to the discovery of relatively straightforward principles that produce reliable learning gains, but have yet to make their way into everyday educational practice. In recent years, the urgent need to improve educational outcomes has led to an increased volume of educationally-relevant research on human cognition, and the time is right to take stock of these findings and what they can offer. The 15 articles in this special issue highlight recent findings from studies of human cognition that can be applied in low-maintenance and cost-effective ways toward improving educational outcomes.

Addressing the topic of mathematics learning in children, Segal, Tversky, and Black (2014) demonstrate that physical actions can facilitate performance. First- and second-grade children performed better on mathematics tasks when they carried out actions that were congruent with the nature of those tasks. For example, in learning how to estimate the location of a value (e.g., 64) on a continuous number line (0–100), children who dragged a marker across the number line estimated the location better than children who simply pointed to the location of the value. Using particular types of actions as part of the learning process, therefore, could be an effective and straightforward way to promote early learning of mathematics skills.

Other studies in this special issue explore the effectiveness of certain approaches to learning that may be highly intuitive, but have yet to be tested empirically. According to survey reports on students' study habits, flashcards are commonly listed among the techniques that students use while studying for exams at the middle- and high-school levels (Agarwal, D'Antonio, Roediger, McDermott, & McDaniel, 2014) and beyond (Yan, Thai, & Bjork, 2014). Given the need to learn multiple different topics, should students pool their flashcards together and study different subjects at the same time, or does this create confusion that impairs learning? Hausman and Kornell (2014) addressed this question and found that it does not appear to matter. Participants who studied two topics together (foreign language vocabulary and anatomical definitions) retained the material from both topics over a one-week period just as well as those who studied them separately.

A wealth of laboratory data has demonstrated that practicing to retrieve information leads to significant learning gains over simply re-reading the information (Roediger & Pyc, 2012, *Journal of Applied Research in Memory & Cognition, 1*, 242–248). However, comparable data are not yet available on the promises—and potential pitfalls—of using retrieval to enhance learning in more complex and diverse environments. Several articles in this special issue address this question. Some find that incorporating retrieval practice into regular course activities significantly improves student learning. For example, Szpunar, Jing, and Schacter (2014) found that the use of periodic quizzes during a statistics lecture improved high-school students' memory for the concepts covered in the lecture. The quizzes benefitted learning in indirect ways as well, by reducing mind wandering and increasing students' note-taking during the lecture. Bjork, Little, and Storm (2014) reported positive effects of quizzing as well on college students' retention of information over a 10-week course on research methods. Students who completed multiple-choice quizzes a few days after each lecture scored significantly higher on the end-of-course cumulative exam than students who did not complete the quizzes. Furthermore, quizzing benefited learning not only of those concepts that appeared on the quizzes (e.g., the directionality problem in interpreting a correlational finding), but also related concepts that did not appear on the quizzes (e.g., the third variable problem in interpreting a correlational finding).

Positive effects of retrieval practice are reported among younger students as well, such as nine- to ten-year-old children learning science and geography concepts (Lipko-Speed, Dunlosky, & Rawson, 2014), and new vocabulary words (Goossens, Camp, Verkoeijen, Tabbers, & Zwaan, 2014). Kang and Pashler (2014) found that benefits of retrieval practice emerged under conditions in which performance was incentivized, suggesting that even under conditions in which students are motivated to learn, retrieval is more effective than restudy. Metcalfe and Miele (2014) further demonstrated that retrieval practice helps students to correct errors and

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misconceptions in their knowledge. When students answered a question incorrectly but with high confidence, practicing to recall the correct information soon afterward helped students to solidify this correct knowledge and reduced the re-emergence of the original misconception later on.

Other studies highlight individual and situational factors that can reduce the effectiveness of retrieval practice. First, retrieval practice may be less effective if students fail to engage in successful retrieval due to difficulty, lack of interest, or other reasons. Karpicke, Blunt, Smith, & Karpicke (2014) found that initial retrieval of physical science concepts by elementary school children was quite low and did not produce any learning gains. However, when provided with the right amount of scaffolding to guide their retrieval (i.e., shorter amounts of information to retrieve, and questions organized in a relational format), children were more successful at retrieving the concepts, and retrieval led to better retention than restudying the concepts. Second, when given the option to engage in retrieval practice or restudy, learners may choose not to engage in retrieval as often as they should. Using a recitation procedure in which learners could switch back and forth between studying and retrieving content via a computer, McDermott and Naaz (2014) found that learners tended to spend the majority of their time studying instead of retrieving. This result parallels that of the survey research by Yan et al. (2014), who found that only 22% of students reported using retrieval practice as a means to improve their learning. These findings suggest that students, particularly when they are very young, may need a certain degree of guidance to help them engage in retrieval practice, or a certain degree of exposure to it before they can use it most effectively. Indeed, following extended exposure to retrieval practice through a series of classroom-based retrieval activities, 92% of middle- and high-school students in the study by Agarwal et al. (2014) endorsed retrieval practice as a technique that helped them learn their course material, 70% of students believed it helped prepare them for exams, and 72% reported a reduction in test anxiety as a result of retrieval practice.

Even when retrieval is effective for retaining knowledge, its effects on transferring knowledge may be less straightforward. Wooldridge, Bugg, McDaniel, & Liu (2014) found, for example, that college students' learning of biology concepts benefitted more from answering short-answer quiz questions than from highlighting relevant sections of the chapter, but these benefits were limited to those items that appeared on the initial quiz and did not transfer to topically-related material that did not appear on the quiz. Thus, retrieval-induced transfer may not always occur, and may depend on the nature of the materials or the way in which the test is constructed. In the study by Bjork et al. (2014) demonstrating positive effects of retrieval on transfer, the quiz questions may have been more likely to activate the non-quizzed information, as quizzed and non-quizzed questions were drawn from the same concept (e.g., two different types of problems in interpreting a correlational finding), and answers to the non-quizzed questions appeared as lures for the multiple-choice questions that appeared on the quizzes. These studies suggest that there may be important points to consider in designing quiz questions in a way that is most likely to enhance the learning of related, non-quizzed information.

When students retrieve information on a quiz or assignment, an important question facing instructors is how quickly they should provide feedback to the students. Despite the seemingly intuitive assumption that feedback is most effective when provided as soon as possible, Mullet, Butler, Verdin, von Borries, & Marsh (2014) found that students' exam scores in a college-level engineering course were significantly higher as a result of receiving feedback one week after they completed the assignment than on the same day they completed the assignment. Despite students' preferences to receive the feedback immediately, receiving it after a one-week delay—a reasonable time frame for returning graded work in a course—led to superior learning.

Finally, it is important to note that the effectiveness of any technique depends on the learner's willingness to use it. Even if learners have good awareness of what helps them learn, they may not always translate that awareness into action. Sussan and Son (2014) found that high school students were good at picking out which biology concepts they needed to study more. However, conditions that increased students' intentions to study did not affect the time that students actually spent studying, nor did it affect how much of the material they ultimately learned. Thus, perhaps equally important to teaching students about proper techniques is the need to ensure that they follow through with *using* those techniques.

It is hoped that the findings from this special issue can be of value to students and educators, and will stimulate further research on applying cognitive principles to education. Moving forward in a world of ever-changing educational policies, advancing technology, and increasing availability of products claiming to expedite learning, there is an ongoing need to recognize empirically-validated principles that reliably affect student learning. These principles do not come in shiny packages, nor do they offer a miracle cure for the problems facing education, but they represent cost-effective and low-maintenance approaches that are capable of enhancing student learning in predictable ways. I hope this collection of articles inspires continued efforts toward identifying and adopting evidence-based approaches for enhancing student achievement.

It has been a delight to serve as guest editor for this special issue. I thank Ron Fisher, editor-in-chief of JARMAC, for inviting me to edit this issue. I also wish to thank the authors for their excellent contributions, and a long list of anonymous reviewers for their suggestions and constructive comments. The articles in this special issue are stronger thanks to their expertise, hard work, and dedication to high-quality research relevant to education.

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