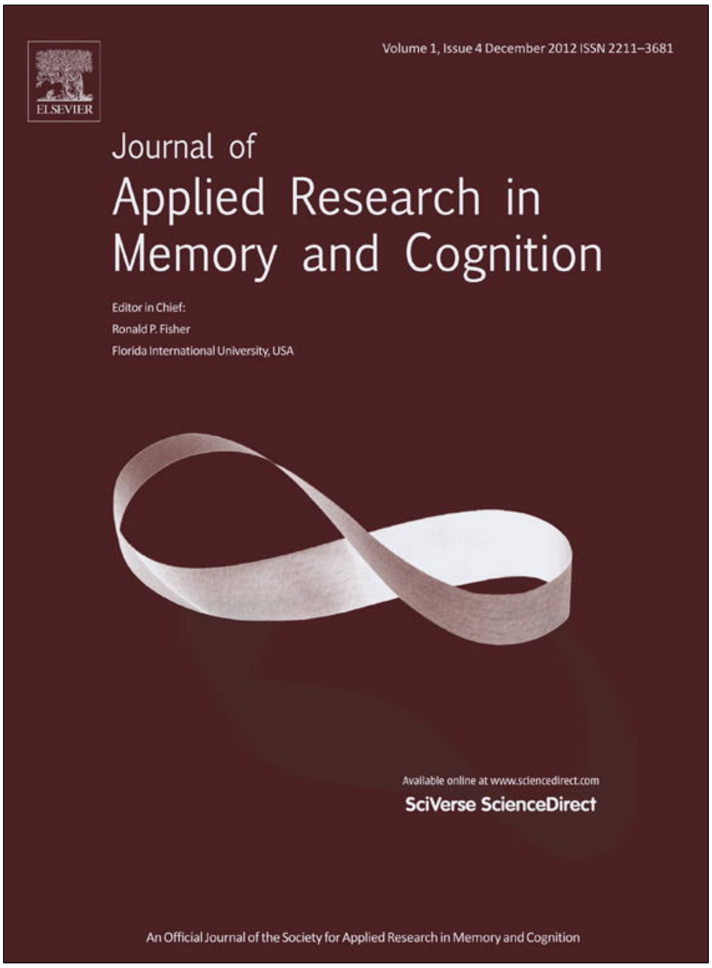
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Target Article

Inexpensive techniques to improve education: Applying cognitive psychology to enhance educational practice

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ABSTRACT

The need to improve the educational system has never been greater. People in congress and business argue for expensive technological applications to improve education despite a lack of empirical evidence for their efficacy. We argue that one inexpensive avenue for improving education has been largely ignored. Cognitive and educational psychologists have identified strategies that greatly improve learning and retention of information, and yet these techniques are not generally applied in education nor taught in education schools. In fact, teachers often use instructional practices known to be wrong (i.e., massing rather than interleaving examples to explain a topic). We identify three general principles that are inexpensive to implement and have been shown in both laboratory and field experiments to improve learning: (1) distribution (spacing and interleaving) of practice in learning facts and skills; (2) retrieval practice (via self testing) for durable learning; and (3) explanatory questioning (elaborative interrogation and self-explanation) as a study strategy. We describe each technique, provide supporting evidence, and discuss classroom applications. Each principle can be applied to most subject matters from kindergarten to higher education. Applying findings from cognitive psychology to classroom instruction is no panacea for educational problems, but it represents one helpful and inexpensive strategy.

A front-page article in the Sunday New York Times (Gabriel & Richtel, October 11, 2011) examined the role of technology in the classroom. Many products have been offered to improve education with an estimated annual cost of $2.2 billion. Yet a survey from the Department of Education in 2010 showed either no or only modest gains from expensive educational products compared to similar classes that used standard textbooks. Of course, new educational products are often not sold on the basis of solid research results showing their effectiveness, but on marketing, personal testimonials, small case studies and the like. The one guaranteed outcome is large profits for the companies that make the products; educational gains for students are more doubtful. Nonetheless, some companies (Intel) and some in the U.S. Congress argue that one goal should be to put a computer in every child's hands in the U.S. That step would be enormously costly. Would children be able to successfully use the computers to improve educational achievement? What studies show this to be the case? We suggest large-scale trial experiments should be undertaken before taking such expensive steps to show their effectiveness. Much more research is needed to show how and when computer-based education is effective so as not to waste funds. As it is, teachers are being laid off, schools are being closed, and so cost-effectiveness is at a premium.

The gold standard of educational innovation for any kind of new educational technique should be a strong research base showing that the new method produces positive results relative to standard practice (Whitehurst, 2010). We do not doubt that someday computer-based education will meet this criterion, but we do not seem to be there yet. Perhaps we should save our money until controlled field experiments produce strong results. We argue that there is much low-hanging fruit to collect before dreaming of sky-high bonanzas that may turn out to be false.

The turn to expensive educational interventions is in some ways not surprising: the problems confronting school officials are enormous, so educators seek help any place they can. Because the problem is huge, the assumption seems to be that all solutions will be correspondingly expensive. Referring to school administrators and teachers, Peter Cohen, a chief executive of Pearson School, commented in the New York Times article that "They want the shiny new. They always want the latest, when other things have been proven the longest and demonstrated to get results" (p. 22).

Below we discuss methods arising from the laboratories of cognitive and educational psychologists that have been shown to produce positive effects on learning. The three basic principles we recommend in this article are ones for which there is

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strong basic (laboratory) research but also research with educational materials and, in some cases, evidence from research in the classroom. The specific techniques that fall under each of the general principles are, for the most part, dirt cheap (little or nothing to buy) and can be incorporated into standard classroom practice without too much difficulty. Yet, outside of educational and cognitive psychology, the techniques are practically unknown. Some teachers and students hit upon these methods on their own through trial and error, but in our (admittedly haphazard) survey of teacher training programs and the curricula of education schools, new teachers are unlikely to be taught about these effective techniques.

Professors in schools of education and teachers often worry about creativity in students, a laudable goal. The techniques we advocate show improvements in basic learning and retention of concepts and facts, and some people have criticized this approach as emphasizing "rote learning" or "pure memorization" rather than creative synthesis. Shouldn't education be about fostering a sense of wonder, discovery, and creativity in children? The answer to the question is yes, of course, but we would argue that a strong knowledge base is a prerequisite to being creative in a particular domain. A student is unlikely to make creative discoveries in any subject without a comprehensive set of facts and concepts at his or her command. There is no necessary conflict in learning concepts and facts and in thinking creatively; the two are symbiotic. As Robert Sternberg and Elena Grigorenko have commented, "Teachers need to put behind them the false dichotomy between "teaching for thinking" and "teaching for facts," or between emphases on thinking or emphases on memory. Thinking always requires memory and the knowledge base that is accessed through the use of memory. ...One cannot apply what one knows in a practical manner if one does not know anything to apply" (Sternberg & Grigorenko, 2003, p. 215). The techniques we advocate below aim to build this knowledge base. We firmly believe, and some empirical evidence shows, that students who can retrieve a variety of information when seeking to solve a problem will show better transfer on that problem than students without such information.

1. Cognitive strategies in enhancing learning

For many years educational and cognitive psychologists have studied factors that improve learning and retention, so that a solid factual basis has been achieved about which strategies work and which ones do not work. A recent review by Dunlosky, Rawson, Marsh, Nathan, and Willingham (in press) examined 10 promising strategies to improve learning in educational situations (see also Mayer's (2010) excellent book and the practice guides published by Pashler et al. (2007)). Based on an exhaustive review, Dunlosky et al. concluded that five strategies they examined were useful and five were not (or had not yet been proven to be useful based on empirical research – future research might change that state of affairs, of course).

In this article, we advocate five of the most useful techniques distilled from their exhaustive review, although we collapse their five strategies into three general principles (grouping closely related ones together). The three general principles we identify are the distribution (spacing and interleaving) of material and practice during learning; the frequent assessment of learning (direct and indirect positive effects of quizzing and testing); and explanatory questioning (elaborative interrogation and self explanation; having students ask themselves questions and provide answers or to explain to themselves why certain points are true). We grouped spacing and interleaving together because they usually go together naturally in practice (information that is interleaved necessarily involves spaced practice), and also consider elaborative interrogation and self explanation as related ideas, although we describe some differences below.

1.1. Distribution of material and practice

Repetition of information improves learning and memory. No surprise there. However, how information is repeated determines the amount of improvement. If information is repeated back to back (massed or blocked presentation), it is often learned quickly but not very securely (i.e., the knowledge fades fast). If information is repeated in a distributed fashion or spaced over time, it is learned more slowly but is retained for much longer. (When other types of learning are interspersed during the times between repetitions of the same information, this condition is referred to as interleaving of practice, as we discuss below.) Although spaced and interleaved presentations of information (or practice on problems) results in slower initial learning, a large body of research shows that it leads to more durable learning and retention.

The spacing effect is one of the oldest findings in experimental psychology (first reported by Ebbinghaus in 1885), and a huge volume of research since then has confirmed the point (see Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006). As noted, both spacing and interleaving impose a time delay between practice trials with the same (or same type of) repeated material. The primary difference between the two is the type of information that is practiced in between presentations of the same information (or practice on the same type of problems). For spacing paradigms, the target information to be repeated is simply spaced out in time (say a fact might be studied every 5 min) with irrelevant activity during the 5-min periods. For interleaving of practice, students study completely different examples of a given concept or topic that are spaced across time (e.g., in math, students would solve various types of problems all mixed up, so that practice on any one type of problem is spaced but with other types of problems occurring between examples of the same type). Both spacing and interleaving have positive effects, as we discuss below, and they are often used together (see Rohrer & Pashler, 2010).

Although the majority of research on spacing and interleaving has been conducted in laboratory settings, the utility of spacing has also been evaluated in classroom settings (e.g., Carpenter, Pashler, & Cepeda, 2009; Sobel, Cepeda, & Kapler, 2011). For example, in a study reported by Bloom and Shuell (1981), high school students learned 20 French–English vocabulary words. Students had 30 min to learn the vocabulary words. Half of the students spent 30 consecutive minutes studying (massed group), whereas the other half studied for 10 min across three consecutive days (spaced group). At the end of the learning phase students had a test to evaluate how much they had learned, and one week later they were given a surprise test to evaluate their long-term retention. The results are shown in Fig. 1, where it can be seen that on the initial test the groups performed similarly; however, on the final test recall was greater in the spaced versus massed group.

Translating this sort of question into the classroom, we can ask: Should students study all material from a given topic before moving on to the next one, or should topics be intermixed? The typical classroom procedure is to give students a new procedure (say second graders learning how to subtract) and then give them many example problems on this procedure to make sure they know it. This produces children who more quickly learn to subtract (if all they have to do is subtract). However, once they have finished studying the four basic procedures of arithmetic, they will have to use those procedures in many different contexts and it will be important to know how to subtract (or multiply or divide or add) in the right context. Blocked presentation may not help the student to pick which operation is needed for the problem at hand.

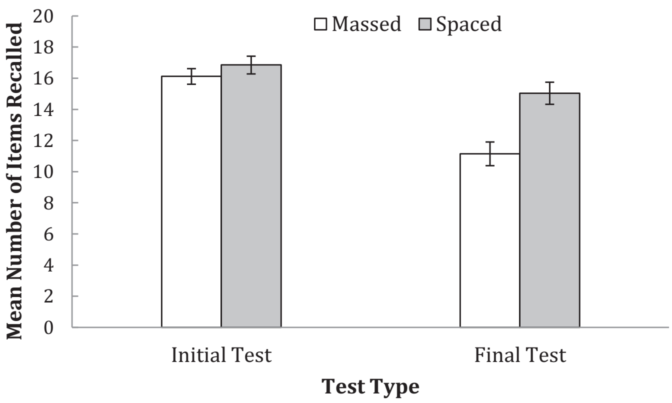

Fig. 1. Mean number (out of 20) of items recalled on initial and final tests for massed and spaced groups (from Bloom & Shuell, 1981).

On the other hand, if the children have experienced interleaved practice (multiplication, addition, subtraction and division problems all mixed together), then they are more likely to succeed later. Research on interleaving suggests that such mixed practice is superior, because enhanced performance occurs on delayed tests after students have experienced interleaved practice as compared to blocked practice (e.g., Kang & Pashler, 2012; Mayfield & Chase, 2002). As noted above in our hypothetical example using arithmetic, this benefit from interleaving may occur in part because interleaving enhances discrimination between item types (and hence knowing what operations to apply).

For example, Taylor and Rohrer (2010) had fourth grade students learn to solve different types of math problems, so that when they were provided with a minimal amount of information (i.e., the number of base sides of a prism) they could determine the number of faces, corners, edges, and angles of the prism. During practice, students solved examples of each problem type using interleaved or blocked schedules of learning. A day later, students were given a novel question for each problem type. The results of the blocking versus interleaving manipulation given during original learning as they affected performance a day later are shown in Fig. 2. The results showed that on the initial tests, performance was better for the blocked (or massed) practice group than for the interleaved group – blocked practice produced better performance on the problems than did spaced practice during learning. However, on the final test given just a day later, this difference reversed; the group that learned with interleaved practice showed greater retention than did the group that learned with blocked practice. Note that

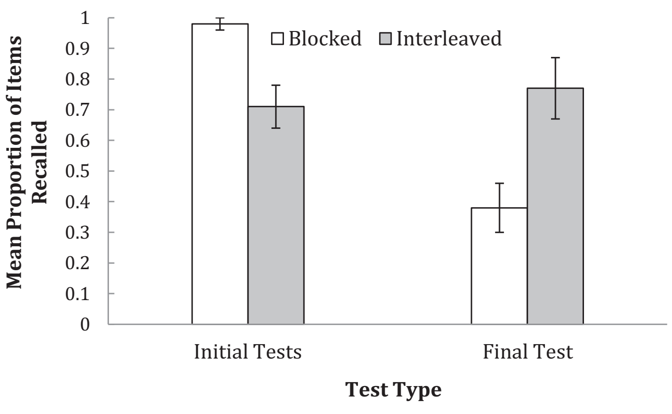

Fig. 2. Mean proportion of items recalled on initial and final tests for blocked and interleaved practice groups (from Taylor & Rohrer, 2010).

this effect occurred despite the fact that blocked practice appeared to produce superior initial learning. Further analyses showed that interleaved practice produced fewer discrimination errors relative to blocked practice; that is, students were better able to determine what type of problem they were dealing with and to apply the correct solution following interleaved practice. This is doubtless because interleaving required students to practice the skill of discriminating the types of problems during initial learning whereas blocked practice did not provide this opportunity because all problems solved in a group were similar. So, once students learned to solve the first problem or two, they could just keep repeating the procedure without discriminating what problem type was represented.

The pattern of results shown in Fig. 2 conforms to a pattern that Schmidt and Bjork (1992) referred to as exemplifying the concept of desirable difficulties (see also Bjork, 1994). Briefly, this term refers to the counterintuitive fact that often procedures that produce fast learning can produce fast forgetting, and that a more difficult procedure in initial learning can lead to greater long-term retention; hence, the initial difficulty is seen as desirable in the long term. Fig. 2 shows a striking example. Schmidt and Bjork pointed out that several variables show similar patterns of effect to spacing and interleaving experiments. Once again, this pattern occurs when some variable that has no effect or even a positive effect during initial learning turns out to have a negative effect on a delayed test. So, for example, we see in Fig. 1 that massed practice and spaced practice have the same effect in foreign language learning on an immediate test, but the spaced condition produced better performance on a delayed test. In Fig. 2, massing or blocking practice improved initial learning relative to interleaving, but interleaving produced better recall after a day.

These outcomes show why teachers and students can be fooled into using strategies that are inefficient in the long run. When we learn we are so focused on how we are learning, we like to adopt strategies that make learning easy and quick. Blocked or massed practice does this. However, for better retention in the long run, we should use spaced and interleaved practice, but while we are learning this procedure seems more arduous. Interleaving makes initial learning more difficult, but is more desirable because long-term retention is better.

Distribution (spacing) of practice and interleaving of examples can be rather easily incorporated into the classroom by teachers and into study routines by students. Teachers can incorporate distributed practice into students' learning by reviewing topics covered in previous lectures at the beginning of each class and/or giving homework assignments that include items from previous chapters. Thus, even if the book covers one topic and then gives blocked practice on examples, teachers can remind students of prior types of problem before the next class on the new type; in addition, homework assignments or in class exercises can mix up the types of problems after students have been exposed to them all, which will require the students to learn to discriminate among problem types.

For students, distributed practice can be accomplished by mixing up topics within a particular domain during periods of studying. For example, a student might mix together concepts from different chapters covered in a biology course to study for an upcoming exam. Might it be even more beneficial to intermix study on entirely different topics, such as biology and history? The evidence on this matter is not yet at hand. Similarly, for concepts and facts, as we shall discuss below, students can make (or buy) flashcards and study any particular card at spaced intervals. Once an item has been practiced (preferably with retrieval practice, see below) it should be placed at the back of the deck of cards and reviewed again, after time has passed, to provide spaced practice.

Students can design study regimes for their particular subject matters with the principles of spacing and interleaving in mind and try to develop strategies to employ them rather than doing what is most natural, viz., to block practice until one has mastered a subject. Blocked practice (especially just before a test) is often referred to informally as cramming, and psychologists have known for a long time that it is a strategy effective only in the short term. In *Principles of Psychology*, William James wrote "The reason why *cramming* is such a bad mode of study is now made clear [from his prior remarks] . . . Things learned in a few hours, on one occasion, for one purpose, cannot possibly have formed many associations with other things in the mind. Their brain-processes are led into by few paths, and are relatively little liable to be awakened again. Speedy oblivion is the almost inevitable fate of all that is committed to memory in this simple way" (James, 1890, p. 445). We shall see more evidence in line with James's dictum in the next section.

1.2. Test-enhanced learning: the importance of continual assessment

Tests are usually considered mechanisms for measuring what has been learned in a course. However, a large amount of research in the past 20 years has shown that the act of taking a test does not simply measure what has been learned but solidifies that learning. Gates (1917) pointed to the importance of "recitation" or retrieval in enhancing learning, and many other studies have followed suit (see Roediger & Karpicke (2006a) for a review). In research in this tradition, students study some material and then one group takes a test (recognition or recall) and a control group either does not take a test (the no test control) or restudies the material (the restudy control). The usual outcome is that the group that takes the test performs better on a second test occurring some time later compared either to the no study control condition or even to the restudy control condition. This outcome is especially likely when feedback is given on the test and when the final criterial test on which performance is measured is delayed. This basic finding has led to an approach called test-enhanced learning (McDaniel, Roediger, & McDermott, 2007) or retrieval-based learning (Karpicke & Grimaldi, 2012).

Roediger and Karpicke (2006b) gave students passages to read with instructions that they would later be tested on those passages. In one condition, they read the passages during four separate periods (denoted SSSS for repeated study). In another condition, they read the passages during three periods and then took a single test (SSST). In the third condition, the students studied the passage only during one period but then took three successive tests (STTT). The tests were free recall tests; students were simply asked to recall the passage as well as possible and they were scored on the number of idea units (basic pieces of information) they were able to recall. Of course, in the cases where students took tests, they could not recall all the information whereas in the cases in which the passage was restudied, 100% of the information was restudied. So, if anything, the deck is stacked against finding effects of testing or retrieval practice in this kind of experiment.

After the part of the experiment described so far, students were asked to predict (on a 7-point scale) how well they would do on a final test to be given a week later. Students predicted best recall in the SSSS condition and least recall in the STTT condition, with the third condition being intermediate. Taking one test or three tests showed students how hard it was to recall the information, whereas simply reading it many times made it seem as if they knew it really well. Students felt fluent in knowing the information.

Groups of students who had learned in these three conditions (SSSS, SSST, and STTT) received one final test either after only five minutes or, as promised, after a whole week. Their results (free recall of idea units) are shown in Fig. 3. Note that the results in the left panel of Fig. 3, the immediate test, mirror the students' predictions well. Recall was best for the four-study condition (SSSS)

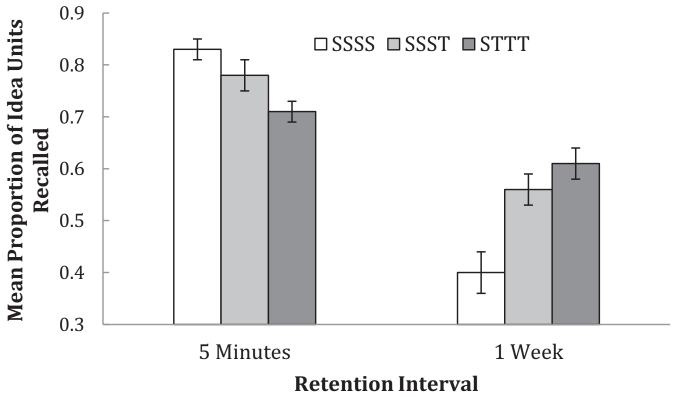

Fig. 3. Performance on immediate and delayed retention tests after learning text passages (from Roediger & Karpicke, 2006b).

and least for the one study and three test condition (STTT). This outcome shows what students have known for time immemorial – cramming right before a test by repeatedly reading material can help you get through the test – the SSSS condition was best. However, the more critical part of the results is shown in the right panel of Fig. 3, the delayed test. Now the pattern seen on the immediate test is completely reversed – students who read the passage only once and took three tests (STTT) did best, those who studied three times and took one test (SSST) did next best, and subjects in the pure study condition (SSSS) with no tests did the worst. Thus, we can see that students learning in the SSSS condition forgot the most over a week and those in the STTT condition forgot the least. This pattern of data confirms William James' point in the quote we used earlier: "Speedy oblivion is the almost inevitable fate of all that is committed to memory in this simple way" (referring to cramming – the SSSS condition in this experiment).

The researchers had asked students to predict how well they would do after a week. Students failed badly in trying to do that getting the order of the conditions reversed. Instead, what their predictions seemed to assess is how well they could remember the information if they were tested immediately, and indeed their predictions did conform to the outcome of the immediate test (the left panel of Fig. 3). Retrieval practice (like spacing and interleaving) thus represents a desirable difficulty – cramming leads to good fast learning, but having tests interspersed leads to better long-term learning. Even though taking practice tests during learning makes initial learning measured shortly afterward worse relative to repeated study, a week later the situation has reversed (Fig. 3). This pattern reveals why students and teachers may have such a difficult time uncovering the factors that lead to good long-term learning, because they usually concentrate on what makes learning good in the short term.

A large number of experiments on retrieval practice have been done in the lab (see Rawson & Dunlosky (2011) and Roediger & Butler (2011) for recent reviews) and in educational settings. In general, retrieval practice is a powerful means of improving retention in learning foreign language vocabulary (e.g., Karpicke & Smith, 2012; Pyc & Rawson, 2010), general knowledge facts (Carpenter, Pashler, Wixted, & Vul, 2008), visuospatial materials (such as maps; Carpenter & Pashler, 2007), science or social science in middle school classrooms (McDaniel, Agarwal, Huelser, McDermott, & Roediger, 2011; Roediger, Agarwal, McDaniel, & McDermott, 2011), statistics and biological basis of behavior at the university level (Lyle & Crawford, 2011; McDaniel, Wildman, & Anderson, 2012) and in medical education (Larsen, Butler, & Roediger, 2009). This is not an exhaustive list, but shows that retrieval-based learning has strong positive effects when applied to education. The process works best when feedback is given after testing (Butler & Roediger, 2008; Cull, 2000), but the effects are often surprisingly powerful even without feedback (Butler, Karpicke, & Roediger, 2008). Still, in educational contexts, giving correct answer feedback after tests is always advisable.

We have emphasized the direct effects of retrieval practice here: retrieving information makes that same information more retrievable in the future and the information can even be used in other contexts, that is it can transfer (e.g., Butler, 2010). However, testing – or, more accurately, continual assessment – has a number of other benefits, too. For example, when students test themselves as part of studying, they learn what they know and what they do not know and they can focus future study efforts on what they do not know. In addition, testing benefits these future study efforts, because research has shown evidence that students learn more from restudying information after taking a test than when they have not taken a test, a process called test potentiation (Arnold & McDermott, in press; Izawa, 1966). Assessment can also have a positive effect on teachers and teaching; when teachers give frequent quizzes, they know what students have learned and what points remain troublesome. This process is called formative assessment in education (Black & Wiliam, 1998). The point is that tests have this indirect effect of helping metacognitive processes in both students and teachers.

In university education, tests are often given infrequently (some classes might have only a midterm and a final exam). Because students tend to bunch their study activities near assessments, that might mean that students only study the material hard a couple of times during the semester. Having continual assessment, even in the form of low-stakes quizzes, keeps students studying the material more regularly during the course (Mawhinney, Bostow, Laws, Blumenfeld, & Hopkins, 1971; Michael, 1991), another bonus of having frequent quizzes or other assessments (e.g., essays). Roediger, Putnam, and Smith (2011) listed 10 benefits of testing, not all of which we have covered here.

The introduction of retrieval practice and assessment is relatively easy to do in both classrooms and in individual studying. In the classroom, frequent low-stakes quizzes (last only 5 or 10 min) can produce a large boost in performance (e.g., Leeming, 2002; Lyle & Crawford, 2011; McDaniel et al., 2011). Of course, the cost is composing the quizzes and grading them, as well as some class time spent in quizzing. However, the evidence shows that the gains are well worth the cost. When university students are asked about study habits, they occasionally mention self-testing or quizzing but they report using other strategies (such as underlining or highlighting and then rereading text) much more often (Karpicke, Butler, & Roediger, 2009). When students do report testing themselves, the reason they give is the metacognitive one – testing helps them to learn what they do not know so as to guide study activities (Kornell & Bjork, 2007). That is a perfectly valid use of testing, but students do not appear to realize the direct benefit that accrues from testing themselves on their ability to retrieve the tested knowledge in the future. Self-testing (via flashcards or other means) can easily be incorporated into students' study habits once they realize (or are told about) its effectiveness (for a summary of how and when students use flashcards to study, see Wissman, Rawson, & Pyc, 2012).

1.3. Explanatory questioning

The final principle that can be incorporated in the classroom (or home study) to enhance learning and retention involve the implementation of explanatory questioning while students are learning. Here we focus on two related techniques that are treated somewhat separately in the psychological and educational literature, elaborative interrogation and self-explanation. Elaborative interrogation involves students generating plausible explanations to statements while they are studying (i.e., answering *why* some stated fact may be true). For example, if they learn that it takes Neptune longer than Mars to revolve around the sun, they should ask themselves why this is the case. By trying to answer the "why" question, the students have to think the issue through to understand it and then they will remember it better.

Self-explanation involves students monitoring their learning and describing, either aloud or silently (i.e., to themselves), some features of their learning. For example, while reading a new page of text, they might be asking themselves: What facts on this page do I already know? What facts are new? Obviously, the elaborative interrogation and self explanation are related because both strategies encourage or even require students to be active learners, explaining the information to themselves (perhaps rephrasing in language they understand better) or asking themselves why the information is true. Of course, retrieval practice also requires active learning, as people learn to retrieve information.

Empirical evidence supports the effectiveness of elaborative interrogation (e.g., Pressley, McDaniel, Turnure, Wood, & Ahmad, 1987) and self-explanation (e.g., Berry, 1983) in measures of learning, relative to reasonable control conditions. Both strategies slow reading (relative to simply zipping through the text, as some students do), but they improve comprehension and learning. Although these strategies have received less attention in the literature compared to the others we have discussed so far, the benefits of explanatory questioning have been documented across a variety of ages and ability levels (Chi, de Leeuw, Chiu, & LaVancher, 1994; Schworm & Renkl, 2006; Scruggs, Mastropieri, & Sullivan, 1994; Smith, Holliday, & Austin, 2010; Wood & Hewitt, 1993).

For example, Smith et al. (2010) evaluated the efficacy of explanatory questioning in a lab section of a Biology course. Students were required to read a chapter from their textbook that had not been previously learned (e.g., a passage on digestion). In one group, they were intermittently prompted to answer questions about recently stated facts (e.g., Fact: Saliva must mix with food to initiate digestion. Question: Why is this true?) In the other group, students were simply told to read through the text twice, as a general control for the amount of time spent on the task. On a final true/false test about facts from the chapter (ones not previously questioned in the elaborative interrogation group), performance was greater for students who engaged in elaborative interrogation relative to reading (twice) for meaning (76% versus 69% correct on the test). Of course, it would be no surprise if elaborative interrogation improved retention for the questioned facts (and it does), but reading in this manner also causes students to improve their comprehension even of parts of the passage that were not covered by direct explanatory questions.

Similarly, with regard to self explanation, Wong, Lawson, & Keeves (2002) evaluated the benefit of this technique in a classroom of students enrolled in a ninth grade math course. Students were given a theorem that they had not yet covered in class and were asked to "think aloud" while studying the information in the book. In one group, after every few sentences students were prompted to self-explain things such as "what parts of this page are new to me?" whereas students in another group were simply instructed to think aloud while studying. One week later all students were provided with a brief overview of the theorem they had learned the week before, with the overview the same for students in both conditions. Then, one day later, they completed a final retention test that measured both near transfer (answering very similar questions to those practiced) and far transfer (making the students apply the same principles on quite different problems). Interestingly, performance in the two conditions did not differ for the near transfer questions, but the self-explanation group was significantly better in answering questions that measured far transfer. This is notable because the far transfer questions involved problems that were quite different from the ones the students had originally studied and indicates that self-explanation can provide the kind of deep learning that permits such transfer.

Of course, these strategies emphasizing questioning during learning cannot be used in all learning situations (e.g., students learning new vocabulary in a foreign language course – retrieval practice or distributed practice are better there). For text material, though, these techniques are quite effective (even though the cost is that they do slow reading). Both explanatory questioning and self-explanation represent relatively easy techniques to enhance learning and comprehension of new material, either in classroom situations or while studying outside of class. Further, both techniques can be used for studying individually or in small groups. The primary requirement is that students actively engage in the learning process by either (1) explaining why (a fact is true) or (2) explaining some processing component of a task, both of which encourage students to incorporate prior knowledge when learning new material.

2. Developing effective learning strategies

The five techniques for improving learning that we have discussed above – spacing and interleaving of practice, retrieval practice (testing), and explanatory questioning and self-explanation – are ones that Dunlosky et al. (in press) showed to have the greatest utility in their comprehensive review. However, other techniques exist for studying and learning, and researchers have evaluated these, too.

When students are given questionnaires to ask what techniques they use to study, two that are usually the most frequent are rereading of text material (or notes from class) and highlighting or underlining (Karpicke et al., 2009; Kornell & Bjork, 2007). A typical strategy is for a student to highlight (or underline) what are perceived to be important points in the text and then, when studying for the exam, to reread the highlighted (or underlined portions). Unfortunately, when Dunlosky et al. (in press) reviewed the evidence on rereading via highlighting and underlining, they found this family of techniques to be relatively ineffective. Thus, students should be warned that simply reading and rereading is much less effective than other study techniques like the ones listed above, and they should be encouraged to use the latter.

We can analyze the material we covered in the previous sections to see how this typical strategy should be augmented. Reading text material is, of course, critical for learning, but students need to do so in an effective manner. Reading should be accompanied by self-explanation and reflection (what new am I learning on this page? How can I relate this material to what I already know?) as well as trying to answer why what is being read is true (again, relating new information to what is already known). These strategies may slow reading, but they make it more active, reflective, and effective. Similarly, students should write down critical questions as they go through a chapter (turn the material into a question format, even if a general one such as "how does photosynthesis work?"). Then these questions can be used later for self-testing and promoting active retrieval. Finally, such self-testing should be done in a distributed manner, with feedback, with different topics interleaved among one another. A study regime such as the one outlined here would lead to more effective learning that would last longer and transfer better to novel tasks than the strategies that students typically employ. As we have also noted, these techniques can usually be employed in the classroom without too much difficulty.

We have highlighted the advantages of five techniques (exemplifying three general principles) for improving education. However, we should also note that there are some situations in which these techniques might not be ideal. For example, certain materials are more amenable to some techniques compared to others (e.g., for learning foreign language word pairs spacing, interleaving, and testing would work well, but explanatory questioning might not). Additionally, we have focused on techniques ideal for long-term retention, given our interest in student learning. These same techniques, however, may not be beneficial if a final retention test is administered immediately. For some purposes, cramming might be all you need to get you through (e.g., looking up a phone number and remembering it long enough to punch in the numbers).

Although each of the effective techniques differ from one another to a greater or lesser extent, they all share a common characteristic in relation to learning and retention; each leads to relatively slow initial learning, but relatively enhanced long-term retention. Thus, one cost of each technique is additional time and effort to initially encode items. However, we argue that the pay-out is great, with enhanced long-term retention that is critical for promoting future learning.

Each of the above described techniques has been empirically validated as being effective in the laboratory and, often, in classroom settings. However, more research would be beneficial to further flesh out boundary conditions of each technique. Future work is also needed to better understand how transfer plays a role in classroom settings as the majority of work presented here is focused on recall of previously learned materials (see Rohrer, Taylor, & Sholar (2010) for a study evaluating transfer in a classroom setting). As mentioned earlier, the construction of a solid knowledge base is critical for promoting creative synthesis; if the knowledge base is lacking then further synthesis will likely not occur.

3. Conclusion

Education is (and has been) in crisis in the U.S. and certainly can be improved in every country. The techniques advocated here for individual study and for classroom practice are by no means panaceas, but we believe they should be useful tools to make learning more effective. One problem is that the use of these techniques requires a motivated learner – a student who wants to learn the material. Many students do not meet this criterion, of course, and motivating students represents a difficult challenge (but one outside the scope of this paper). Similarly, other difficult issues – children coming from impoverished homes that lack parental support, hunger, a lack of readiness for school – are all critical issues that our methods do not begin to solve. Nonetheless, once the child arrives at school, the techniques we have described should enhance learning and they have the additional benefit of being nearly free in terms of expensive equipment or huge investments of time. Most can be readily incorporated into classroom practice or study regimes.

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