Spaced Repetition Promotes Efficient and Effective Learning: Policy Implications for Instruction

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Spaced Repetition Promotes Efficient and Effective Learning: Policy Implications for Instruction

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Abstract

Concern that students in the United States are less proficient in mathematics, science, and reading than their peers in other countries has led some to question whether American students spend enough time in school. Instead of debating the amount of time that should be spent in school (and on schoolwork), this article addresses how the available instructional time might be optimally utilized via the scheduling of review or practice. Hundreds of studies in cognitive and educational psychology have demonstrated that spacing out repeated encounters with the material over time produces superior long-term learning, compared with repetitions that are massed together. Also, incorporating tests into spaced practice amplifies the benefits. Spaced review or practice enhances diverse forms of learning, including memory, problem solving, and generalization to new situations. Spaced practice is a feasible and cost-effective way to improve the effectiveness and efficiency of learning, and has tremendous potential to improve educational outcomes. The article also discusses barriers to adopting spaced practice, recent developments, and their possible implications.

Keywords

research-based instructional strategies, spaced/distributed practice, testing, learning, education

Tweet

For durable learning, space out your review of the material over time; back-to-back repetitions are ineffective.

Key Points

- The timing or arrangement of review/practice affects learning.
- Practice is more effective when spaced out over time, instead of massed or grouped together (equating total practice time).
- Spaced practice enhances memory, problem solving, and transfer of learning to new contexts.
- Spaced practice offers great potential for improving students' educational outcomes.

Introduction

Every few years, when the results of international assessments of students' mathematics, science, and reading proficiency (e.g., Trends in International Mathematics and Science Study, Programme for International Student Assessment) are released, there is renewed consternation that American students lag behind their peers in other countries. Many factors have been proposed to explain the differences in educational outcomes among participating countries, including cultural attitudes toward education (e.g., Jensen, Hunter, Sonnemann, & Burns, 2012; Pearson, 2012). One question debated in the United States for decades is whether children spend enough time in school (Barrett, 1990). Although the number of school days per year for American children is relatively low, compared to many other countries, in terms of total instruction hours from primary through lower secondary education, the United States ranks among the highest (Organisation for Economic Co-operation and Development, 2014). What counts as official instruction time, however, varies across countries (and across states within the United States). Also, whether the time is used as intended (for teaching, as opposed to performing administrative or classroom management tasks) and how much additional time is spent on schoolwork outside of school (e.g., homework, after-school tutoring) clearly do matter as well.

Independent of whether sufficient time is devoted to academics (both inside and outside of school), another perhaps more tractable issue (and the focus of this article) is how

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instructional activities are scheduled. Within the available time, can instruction and related learning activities be arranged in a manner that is optimal for learning? Put differently, is student learning affected by the timing of academic activities? A large body of research from cognitive and educational psychology suggests an affirmative answer to both questions. Repeated encounters with to-be-learned material that are spaced out in time (as opposed to recurring back-to-back) are an effective way to foster learning that is long lasting. Incorporating spaced repetitions into existing educational practice is feasible and has great potential to produce gains to learning without requiring added resources (time or money).

The Spacing Effect

Most people know from personal experience that if one is trying to learn something well—be it a set of facts, concepts, skills, or procedures—a single exposure is usually inadequate for good long-term retention. We are all familiar with the adage "practice makes perfect." But what is less obvious is that the timing of the practice (*when* it occurs) matters a great deal: Having the initial study and subsequent review or practice be spaced out over time generally leads to superior learning than having the repetition(s) occur in close temporal succession (with total study time kept equal in both cases). This phenomenon is called the *spacing effect* (sometimes also referred to as the benefit of *distributed practice*) and was first observed by researchers over a century ago (Ebbinghaus, 1885/1913). Since that time, literally hundreds of experiments by cognitive psychologists have demonstrated the advantage of spaced/distributed over massed practice (Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006), and a recent comprehensive review of the utility of various learning strategies awarded distributed practice one of the highest ratings based on the available research evidence (Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013). Figure 1 shows a commonly used design for studying the spacing effect when there is a single review opportunity.

Spaced Practice Benefits Memory

Probably the most robust effects of spacing occur in improved rote memory for the studied material. Across 254 studies comparing massed versus spaced practice on later memory for verbal information (e.g., words, sentences, facts, passages), overall, spaced practice dominated massed practice in recall performance (Cepeda et al., 2006). In one early study, to illustrate a specific instance, college students were asked to learn the Athenian Oath (Gordon, 1925). One group of students heard the oath read 6 times in a row; another group heard the oath 3 times on 1 day and 3 more times 3 days later. The students recalled as much as they could immediately after hearing the oath for the sixth time and again 4 weeks later. On the immediate test, the group that

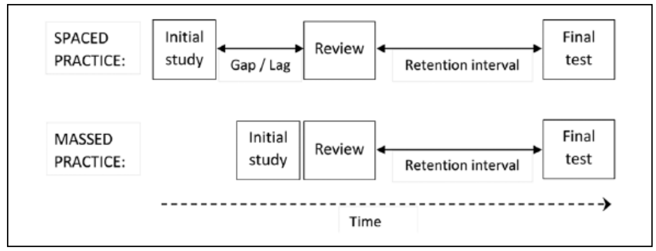

Figure 1. The typical experimental procedure for examining the spacing effect.

received massed repetition recalled slightly more than the group that received spaced repetition. But on the delayed test 4 weeks later, the spaced group clearly outperformed the massed group. While massed practice might appear more effective than spaced practice in the short term, spaced practice produces durable long-term learning (see Rawson & Kintsch, 2005, for similar findings regarding rereading of text passages on immediate vs. delayed recall).

A number of theories may explain the benefit of spaced practice for long-term retention (Toppino & Gerbier, 2014). According to one prominent theory, repeating an item potentially reminds the learner of its prior occurrence, which prompts *retrieving* the previous presentation of the item, a process that enhances memory (e.g., Wahlheim, Maddox, & Jacoby, 2014; the next section elaborates on the effects of retrieving from memory). Massed repetition eliminates the retrieval process—there is no need to retrieve from memory because the same item was just presented. Another theory emphasizes the study/learning *context* (i.e., what surrounds an event, from the external environment to an individual's mental state). With spaced repetitions, the context that gets encoded in memory with each presentation of an item is likely to be more variable (compared with massed repetitions that are close together in time and context); the variable contexts that are stored in memory then serve as more effective cues for subsequent retrieval of the item (e.g., Glenberg, 1979). *Deficient processing* of massed repetitions is yet another theory. When a current item is the same as one that was just presented, the redundancy reduces attention (e.g., Magliero, 1983). The different theories are not mutually exclusive, and multiple mechanisms may act in concert to yield the memory advantage produced by spaced practice.

Few would argue that memorizing instructional content, so as to be able to reproduce the information verbatim from memory, is the ultimate goal of education. Nonetheless, acquiring foundational knowledge and being able to quickly access relevant information from memory are often prerequisites for higher order learning and reasoning. For instance, remembering arithmetic facts (e.g., times table) is a critical part of mathematical skill learning, and a transition from calculation to direct memory retrieval of the answer allows more efficient problem solving (e.g., Siegler, 1988). Spaced practice promotes not only accurate recall of multiplication facts in children (Rea & Modigliani, 1985) but also faster retrieval of target responses (Rickard, Lau, & Pashler, 2008). Also, possessing adequate prior knowledge can facilitate subsequent learning and comprehension (e.g., Kalyuga, 2007; Mayer, 1977). In short, spaced practice can improve students' memory for essential facts and concepts, which in turn facilitates more complex learning and problem solving.

Testing + Spacing = Spaced Retrieval Practice

In a recent issue of this journal, Benjamin and Pashler (2015) argued that testing can be a valuable educational tool for promoting learning (see also reviews by Carpenter, 2012; Karpicke & Grimaldi, 2012; Roediger & Butler, 2011). In brief, testing (or practicing retrieval from memory, relative to just rereading the material) boosts learning in various ways: improved memory for the tested information (e.g., Kang, McDermott, & Roediger, 2007), slowed forgetting (e.g., Carpenter, Pashler, Wixted, & Vul, 2008), transfer of learning to new situations (e.g., Butler, 2010), generalization to new examples (e.g., Kang, McDaniel, & Pashler, 2011), potentiated subsequent learning (e.g., Arnold & McDermott, 2013), and augmented learner metacognition (e.g., Soderstrom & Bjork, 2014). Testing's benefits are not limited to formal tests. Many informal ways of testing engage the same kinds of beneficial processes, and these include using flashcards when studying (e.g., Kornell, 2009) and using "clickers" in class to record students' responses to the teacher's questions (e.g., Anderson, Healy, Kole, & Bourne, 2013). The review of learning strategies cited earlier (Dunlosky et al., 2013) gave practice testing its highest utility rating (the same rating that spaced practice received; no other strategy achieved as high a rating).

Testing or spaced practice, each on its own, confers considerable advantages for learning. But, even better, the two strategies can be combined to amplify the benefits: Reviewing previously studied material can be accomplished through testing (often followed by corrective feedback) instead of rereading. In fact, many studies of the spacing effect compared spaced against massed retrieval practice, not just rereading (e.g., Bahrick, 1979; Cepeda, Vul, Rohrer, Wixted, & Pashler, 2008). Spaced retrieval practice (with feedback) leads to better retention than spaced rereading. One study examined how type of review (reread vs. test with feedback), along with timing of review (massed vs. spaced), affected eighth-grade students' retention of history facts (Carpenter, Pashler, & Cepeda, 2009). On a final test 9 months later, spaced retrieval practice yielded the highest performance (higher than spaced rereading).

Is There an Optimal Spacing Lag?

One might assume that if spaced repetitions are more effective than massed ones, then the longer the lag (between repetitions), the greater the benefit. The research evidence, however, suggests that this assumption is too simplistic. A large experiment examined 10 different lags (the spacing gap between initial learning and retrieval practice review ranged from 0 to 105 days) and four different retention intervals (the final test was administered either 7, 35, 70, or 350 days after the review session; Cepeda et al., 2008). Retention of trivia facts (the study material) was highest when the lag was about 10% to 20% of the tested retention interval (see also Cepeda et al., 2009). In other words, there is no fixed optimal lag—It depends on the targeted retention interval. If you want to maximize performance on a test about 1 week away, then a lag of about 1 day would be optimal; but if you want to retain information for 1 year, then a lag of about 2 months would be ideal.

This example used only a single review opportunity. What about situations with multiple opportunities to revisit the material? Clearly, spacing out the multiple review opportunities produces better learning than massing them together, but there is a debate as to whether the multiple reviews should be equally spaced apart or whether they should occur in an *expanding schedule* (i.e., the lag between each successive review progressively increases; Balota, Duchek, & Logan, 2007). The justification for expanding retrieval practice is that (a) having the early retrieval attempts occur fairly soon after initial learning insures a high rate of retrieval success, and (b) retrieval slows forgetting, so (c) subsequent retrieval opportunities can be pushed farther apart in time, to ensure that practice continues to be effortful and not trivial (Landauer & Bjork, 1978). A study compared expanding and equally spaced retrieval practice (with corrective feedback), separating the practice sessions by days or weeks; the expanding practice schedule yielded higher retention of foreign vocabulary over the extensive training period, suggesting that expanding practice may especially maintain knowledge over long periods of time (Kang, Lindsey, Mozer, & Pashler, 2014). Overall, whether expanding practice produces learning that is superior to equally spaced practice probably depends on factors such as the difficulty of the to-be-learned material, the type of review (rereading or retrieval practice), and the specific time frame (Storm, Bjork, & Storm, 2010).

Spaced Practice Improves Generalization and Transfer of Learning

This review has so far focused on how spaced practice improves memory, in part because memory researchers first observed the spacing effect and also because the majority of prior studies examined memory. Although acquiring and retaining knowledge matters in education, a more crucial objective is *transfer*, the ability to utilize what was learned to answer new questions or solve new problems (after all, in real life the likelihood of encountering material in exactly the same way as presented during instruction is exceedingly low). Mere remembering of content is rote learning, focused on the past; on the contrary, meaningful learning involves transfer and orients toward the future (Mayer, 2002).

Although the research surrounding the benefits of spaced practice for more complex kinds of learning is not as extensive as that for memory, some evidence indicates that spacing can enhance meaningful learning that generalizes to new situations (see Carpenter, Cepeda, Rohrer, Kang, & Pashler, 2012, for a review). In one study, college students attended a 45-min lecture on meteorology and then reviewed the information (in a quiz with corrective feedback) either 1 or 8 days later (Kapler, Weston, & Wiseheart, 2015). On a final test 35 days after the review session, students in the 8-day condition performed better than those in the 1-day condition not just on the factual recall questions but also on the questions that required application of knowledge. Other studies support spaced practice of mathematics problems (Rohrer & Taylor, 2006) and ecology lessons (Gluckman, Vlach, & Sandhofer, 2014; see also Vlach & Sandhofer, 2012). In addition to improving mathematics problem solving and science concept learning, spaced practice benefits the long-term learning of English grammar in adult English-language learners (Bird, 2010). In all cases, the students were not just memorizing solutions but were instead applying their learning to solve new problems.

Spacing and Interleaving

One way to space out repetitions is to intersperse other items in-between repetitions of a given item. For instance, in the sequence ABCABCABC, two intervening items (e.g., B and C) come before each recurrence of a given item (e.g., A). Such an arrangement, in which different kinds of items intermix during practice, is termed *interleaved* practice. In contrast, *blocked* practice groups the same kinds of items together during practice (e.g., AAABBBCCC). While an interleaved schedule does inherently introduce spacing between repetitions, interleaving is a distinct intervention from spacing (Rohrer, 2009).

Interleaved practice (relative to blocked practice) benefits motor skill acquisition, category learning, and mathematics problem solving (for reviews, see Kang, in press; Rohrer, 2012). Examples from the latter two domains are most directly related to academic learning.

Sequencing of examples during training affects visual category learning (e.g., learning to recognize the painting styles of different artists or identify different kinds of birds). Interleaved training (e.g., intermixing paintings by different artists), relative to blocked training (e.g., consecutively presenting paintings by a given artist), enhances learners' ability to accurately classify novel examples (e.g., Kornell & Bjork, 2008; Kornell, Castel, Eich, & Bjork, 2010). Juxtaposition of the different categories (e.g., artists) during interleaved training facilitates noticing the differences among the categories (Kang & Pashler, 2012), which is helpful when the to-be-learned categories are similar or easily confusable (Carvalho & Goldstone, 2014). Additional support for the idea that interleaving promotes discriminative contrast among the categories comes from a study on learning bird and butterfly species (Birnbaum, Kornell, Bjork, & Bjork, 2013). The study also found that temporal spacing could be a factor—interleaving with more (rather than fewer) intervening items from other categories, between successive presentations of a given category, improved learning. Attentional lapses may also play a role. Mind wandering is more likely during blocked than interleaved training (Metcalfe & Xu, in press). Multiple mechanisms may underlie the interleaving advantage: Attention, temporal spacing, and juxtaposing different categories could jointly contribute to learning.

Interleaved practice also benefits mathematics problem solving in college students (Rohrer & Taylor, 2007) and elementary school children (Taylor & Rohrer, 2010). Students after blocked practice had difficulty discriminating among the problem types and knowing when to use which formula. Therefore, similar to category learning, interleaved practice seems to help learners differentiate among the types of problems they are learning to solve.

Spaced and Interleaved Practice in the Classroom

Although most studies on spaced or interleaved practice have been conducted in laboratory settings (for better control over extraneous variables), students in actual classrooms can benefit from instructors using these learning strategies (e.g., Carpenter et al., 2009; Sobel, Cepeda, & Kapler, 2011). A few studies were conducted not only in real-world educational settings but also in the context of a regular curriculum (i.e., instructional manipulation on course content).

In one classroom-based study, the mathematics homework assignments for seventh-grade students were manipulated across 9 weeks (Rohrer, Dedrick, & Burgess, 2014). Ten mathematics assignments were given out over that period, each consisting of 12 practice problems. For topics assigned to blocked practice, all 12 problems in a single assignment would pertain to that one topic (and no other assignment would feature that kind of problem). For topics assigned to interleaved practice, only the first four problems in the assignment would belong to the current topic; the other eight problems in the assignment would cover previous topics; also, the remaining eight practice problems pertaining to the current topic (of the first four problems) would be distributed across future assignments. That is, the total number of practice problems devoted to each topic was equal across the blocked and interleaved conditions (12 practice problems per topic). The only difference was whether all 12 problems on a given topic were completed in one assignment or whether they were spread out across multiple assignments (and therefore interleaved with other types of problems). On a surprise test containing novel problems (on the same topics), given 2 weeks after the final homework assignment, the students were substantially better at solving the types of problems that had been practiced in an interleaved manner than those under blocked practice.

Interleaving has strong benefits even when the problem types were quite different (Rohrer et al., 2014), compared with the earlier studies on mathematics problem solving (e.g., Rohrer & Taylor, 2007). Enhanced discrimination (learning to differentiate the various types of problems) is not the only explanation for the interleaving advantage. During interleaved practice, switching among different problem types may strengthen the association between a problem type and its strategy, which promotes successful problem solving. With blocked practice, on the contrary, as all the problems require the same strategy, the student needs only focus on executing a given strategy repeatedly, which might not be as effective in reinforcing the association between a problem type and its strategy (Rohrer et al., 2014; see also Rohrer, Dedrick, & Stershic, 2015). A similar study conducted within a college engineering course found that spacing out the practice problems on a given topic over 3 weeks produced better performance on the midterm and final exams than having practice problems on a given topic assigned only during the week that the topic was taught in class, which was the standard practice (Butler, Marsh, Slavinsky, & Baraniuk, 2014).

The studies described above are notable for two reasons. First, they were conducted within a regular class (middle school mathematics, college-level engineering). Given that classroom-based studies tend to be more "noisy," due to the lack of control over many variables (e.g., Greene, 2015), the observed effect of spacing/interleaving is impressive. Second, the instructors taught the classes as they normally would have—the topics covered, the lecture content, and the assessments generally remained the same—suggesting that a radical overhaul of teaching practice may not be necessary. Something as simple as reorganizing the homework assignments may be sufficient to produce sizable gains.

Metacognitive Considerations Surrounding Spaced Practice

A recent survey of college students found that the majority seemed to be aware that spaced (rather than massed) study benefits learning (Morehead, Rhodes, & DeLozier, 2016), yet students report frequently massing (or cramming) their study before an exam (e.g., Susser & McCabe, 2013). Also, grade point average (GPA) is correlated with spaced study: Students with higher GPAs more often report spacing their study (Hartwig & Dunlosky, 2012). Probably two broad factors work against students' greater use of spaced practice as a study strategy. The first is the forethought or planning required to space out one's studying (and the concomitant discipline needed to follow through on the plan), which helps explain the discrepancy between an ideal (knowing that spaced study is beneficial) and actual behavior (ending up with massed study). The second factor is the subjective sense of fluency that is often engendered by massed practice, which can mislead the student into feeling large gains in learning (Finn & Tauber, 2015). Of course, as in some of the studies reviewed earlier, these gains do not last. Given that spaced practice is not the default study habit for most students (particularly the ones who are performing poorly), educators could be especially helpful by structuring their pedagogy in a way that encourages spaced review.

Capitalizing on Spaced Practice in Education

Ample evidence supports the utility of spaced practice in improving educational outcomes. Incorporating spaced practice into education can be a cost-effective approach—learning becomes more durable in the same amount of time (relative to massed practice), and this can lead to future savings because less time needs to be spent on relearning content that has been forgotten, leaving more time for other productive learning activities (e.g., higher order analysis, application of knowledge). In short, spaced practice enhances the efficacy and efficiency of learning, and it holds great promise as an educational tool. Despite over a century of research findings demonstrating the spacing effect, however, it does not have widespread application in the classroom. The spacing effect is "a case study in the failure to apply the results of psychological research" (Dempster, 1988, p. 627).

Probably (at least) two major obstacles impede greater implementation of spaced practice in education. When deciding on what instructional techniques to use (and when to use them), many teachers default to familiar methods (e.g., how they themselves were taught; Lortie, 1975) or rely on their intuitions, both less than ideal: Our intuitions about learning can sometimes be plain wrong, and it would be a waste to overlook the growing evidence base regarding the effectiveness of various teaching or learning strategies. A possible solution is for teacher preparation to increase its focus on the science of learning (e.g., how the human mind learns, what factors influence learning, learning strategies, and their relative efficacy).

The second major hurdle is conventional instructional practice, which typically favors massed practice. Teaching materials and aids (e.g., textbooks, worksheets) are usually organized in a modular way, which makes massed practice convenient. After presenting a new topic in class, teachers commonly give students practice with the topic via a homework assignment. But aside from that block of practice shortly after the introduction of a topic, no further practice usually follows, until a review session prior to a major exam. What this means for teachers deciding to incorporate spaced practice in their classrooms is that some planning is required. Complete overhaul of teaching practice may be difficult, but modifying homework assignments is probably an achievable target. The classroom-based studies described earlier (Rohrer et al., 2014; Rohrer et al., 2015) show how a small change in homework assignments—switching from having the practice problems in a given assignment on just one topic, to having a mix of problems pertaining to various topics appearing in each assignment—can dramatically improve mathematics learning.

Despite the challenges, some relatively recent developments could contribute to greater adoption of spaced practice. For instance, the creation of *spiral* curricula for K-12 classes, in which material is revisited repeatedly over months and across grades with increasingly deeper levels of complexity, means that schools and teachers will have better access to teaching resources that incorporate spaced practice as part of the regular curriculum. Also, increasing use of computer technology in education (e.g., e-learning, computerized tutors, and learning management systems) could make it easier for students to engage in spaced retrieval practice that is adaptive or personalized to their individual needs (Lindsey, Shroyer, Pashler, & Mozer, 2014). The use of e-learning platforms might also provide a way to ameliorate the summer "brain drain." Assuming a student has already been engaging in spaced practice over the academic year, a refresher or review session conducted over the Internet during the summer could go a long way in stemming the learning loss that afflicts many students.

At the end of the 19th century, William James (1899) exhorted teachers to encourage spaced practice in their students:

> You now see why "cramming" must be so poor a mode of study. Cramming seeks to stamp things in by intense application immediately before the ordeal. But a thing thus learned can form but few associations. On the other hand, the same thing recurring on different days, in different contexts, read, recited on, referred to again and again, related to other things and reviewed, gets well wrought into the mental structure. This is the reason why you should enforce on your pupils habits of continuous application. (p. 129)

The advice given over a 100 years ago is still completely applicable today, bolstered by the added weight of strong scientific evidence. My hope is that educators will embrace creative ways to foster spaced practice in and outside the classroom for the benefit of their students' learning.

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