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Using Spacing to Enhance Diverse Forms of Learning: Review of Recent Research and Implications for Instruction

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Abstract

Every day students and instructors are faced with the decision of when to study information. The timing of study, and how it affects memory retention, has been explored for many years in research on human learning. This research has shown that performance on final tests of learning is improved if multiple study sessions are separated—i.e., "spaced" apart—in time rather than massed in immediate succession. In this article, we review research findings of the types of learning that benefit from spaced study, demonstrations of these benefits in educational settings, and recent research on the time intervals during which spaced study should occur in order to maximize memory retention. We conclude with a list of recommendations on how spacing might be incorporated into everyday instruction.

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One fundamental decision that students and instructors must make is *when* to study information. If an exam is coming up next week, should students begin to review their notes today, or wait a few more days? Once instructors have presented information, how long should they wait before they review this information in order to increase the chances that students will retain it over summer break? Given that the intended outcome of such decisions is to promote durable learning, understanding how the scheduling of study influences memory retention is critically important.

The benefits of spaced study

Studying information across two or more sessions that are separated (i.e., spaced apart or distributed) in time often produces better learning than spending the same amount of time studying the material in a single session. Figure 1 illustrates the design of a typical study on this topic. This design includes: (1) multiple study sessions in which the same information (e.g., biology terms) is presented at least twice, (2) a manipulation of the time duration between successive presentations, which is referred to here as the *spacing gap*, and (3) a *test delay* that is defined as the time elapsed between the final study presentation and the test. The test delay can either be fixed or manipulated.

When the spacing gap between two or more presentations of the same item is zero (e.g., the same biology term and definition is presented back-to-back with no interruptions in-between), the presentations are said to be *massed* together. When the gap between presentations is greater than zero (e.g., a given biology term is repeated every five minutes, or after five different biology terms have been presented), then the presentations are said to be *spaced* or *distributed* because they are separated by a nonzero time interval. The gap separating spaced presentations can range anywhere from a few seconds to several weeks, whereas the gap separating massed presentations is zero.

On the final memory test, performance is most often better for items that were spaced rather than massed. This is typically referred to as the *spacing effect*. Some studies have also reported that different spacing gaps (i.e., lags) result in different degrees of learning, which has sometimes been referred to as the *lag effect*. For example, learning of a given biology term might be better when it is repeated after a relatively long spacing gap (e.g., five minutes) compared to a relatively short spacing gap (e.g., one minute). In the current paper, we use the term *spacing effect* in a general sense to refer to the different degrees of learning that result as a function of different spacing gaps.

The spacing effect is one of the oldest and most reliable findings in research on human learning. Early demonstrations of this effect date back to over 100 years ago (e.g., see Ebbinghaus, 1885/1913), and hundreds of published studies have reported benefits of spacing (for a recent review, see Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006). While participants in most of these studies were adult learners, the benefits of spacing have also been reliably demonstrated in studies with younger participants, including elementary school children (e.g., Toppino & DiGeorge, 1984), middle school children (e.g., Carpenter, Pashler, & Cepeda, 2009; Toppino & DeMesquita, 1984), and preschool children as young as three or four years of age (e.g., Rea & Modigliani, 1987; Toppino, 1991).

The vast majority of studies on the spacing effect has been conducted in the laboratory, and these studies typically require participants to learn relatively simple types of verbal information such as word lists or trivia facts. Recently, however, new findings have emerged showing that spacing can also improve learning of information that is conceptually more difficult. For example, Bird (2010) found that longer spacing gaps improved English-learning adults' understanding of subtle grammatical rules. Participants saw sentences such as "Albert Einstein has been a great mathematician," and their task was to provide the corrected version, "Albert Einstein was a great mathematician." Two practice sessions were separated by either three or 14 days, and the 14-day spacing gap produced superior scores to the three-day gap on tests given either seven or 60 days later. Spacing has also been shown to improve learning in other tasks that might be considered complex forms of learning, such as spelling (Fishman, Keller, & Atkinson, 1968), reading skills (e.g., Seabrook, Brown, & Solity, 2005), and biology (Reynolds & Glaser, 1964).

Spacing effects were found in two recent experiments in which college students learned a moderately abstract mathematics task (Rohrer & Taylor, 2006, 2007). The task required students to find the number of permutations of a sequence of items with at least one repeated item. For instance, the sequence *abbccc* has 60 permutations, including *abaccc* and *abcbcc*. In both studies, spacing boosted scores on a final test consisting of novel problems of the same kind. Figure 2 shows the results of one of these studies.

Benefits of spacing have also been reported for tasks involving coordinated motor skills. For instance, in a study reported by Moulton et al. (2006), surgical residents practiced microsurgical skills in four training sessions that were squeezed into the same day or distributed across four weeks. On a final test given one month after the last practice session, a spacing effect was found.

Recent studies have shown that spacing can benefit learning in realistic educational contexts as well. In one study, Sobel, Cepeda, and Kapler (2011) investigated fifth-graders' retention for the definitions of uncommon English words of the type that appear on the Graduate Record Examination (GRE) (e.g., abscond: to leave secretly and hide, often to avoid the law). These words were learned in class via a teacher-led tutorial that included slides, oral practice, and paper-and-pencil tests. Either immediately or one week after the first tutorial, students completed the same tutorial a second time, and were then given a final vocabulary test that required them to supply the definition for each word five weeks after completing the second tutorial. Memory on the five-week delayed test was superior for definitions learned with the seven-day spacing gap (20.8%) compared to the zero-day spacing gap (7.5%). This amount of forgetting might appear substantial, but previous research on forgetting of classroom material has demonstrated a similar level of forgetting over a similar time period (Jones, 1923; Tiedeman, 1948).

In a second study, Carpenter et al. (2009) explored how the timing of a review session affected retention of U. S. history facts that were learned by eighth grade students. After completing their course in U. S. history, students completed a review activity that involved answering several questions from the most recent unit that they studied (e.g., Who assassinated president Abraham Lincoln?). For each question, students were asked to write an answer (e.g., John Wilkes Booth), and then were given a sheet of answers to check their accuracy. One group of students completed the review one week after finishing the course (i.e., the Immediate Review Group), and another group completed the same review 16 weeks later, after returning from summer vacation (i.e., the Delayed Review Group). Students were tested over the information again nine months after completing the review. After such a substantial delay, it is not surprising that students forgot the majority of answers to these questions. The key finding, however, was that long-term retention was better for students who completed the delayed review than for those who completed the immediate review (12.2% vs. 8%, respectively).

Another demonstration of the benefits of spacing in the classroom was reported by Seabrook et al. (2005), who assessed first graders' acquisition of reading skills. In their regular classrooms, all students received six minutes of instruction per day for two weeks. One group of students received this instruction within a single session lasting six minutes, while a second group received it across three separate two-minute sessions that were administered at unspecified time intervals. A comparison of pretest and posttest scores revealed that the group experiencing the spaced two-minute sessions showed greater improvement in reading skills (an increase of 8.3 points), compared to the group experiencing the continuous six-minute session (an increase of only 1.3 points).

How long should the spacing gap be?

To use spacing as effectively as possible, it is important to know just how far apart the study sessions should be spaced. For instance, if medical professionals wish to maintain good retention of emergency response skills over a two-year period, is there an optimal time during which they should review these skills? When learners must retain information over a given test delay, an important practical question to address is when repeated study of this information should take place.

If spacing benefits learning, then a reasonable assumption might be that longer spacing gaps would benefit learning to an even greater degree. Indeed, some studies examining the effects of longer vs. shorter spacing gaps have typically found that longer spacing gaps are more beneficial for retention (e.g., Glenberg, 1976; Hintzman, 1969, 1974; Melton, 1970). For example, Kahana and Howard (2005) found that retention of words was best when the words were repeated three times with six to 20 other words occurring between each of the three presentations, compared with only two to six other words occurring between each of the three presentations.

Studies by Bahrick and colleagues examining long-term retention appear to confirm the idea that longer spacing gaps produce better memory retention than shorter spacing gaps. In a study by Bahrick (1979), participants learned the English translations for several Spanish words by completing six learning sessions that were separated by a spacing gap of either zero days (i.e., all sessions occurred on the same day), one day, or 30 days. All participants were given a final test one month after the last learning session. Performance on this test was best for the participants who learned the words with the 30-day spacing gap. A follow-up study revealed that retention of these words after eight years was still superior for the participants who experienced the 30-day spacing gap relative to the zero- or one-day spacing gap (Bahrick & Phelps, 1987).

However, reviews of the literature on spacing have revealed that an increase in the duration of the spacing gap does not always produce superior memory retention (e.g., Cepeda et al., 2009; Cepeda et al., 2006; Donovan & Radosevich, 1999; Glenberg, 1976; Verkoeijen, Rikers, & Özsoy, 2008). One potential danger of waiting too long before reviewing information is that students may forget much of what they have learned previously, and this forgetting may offset any benefits that would have occurred due to spacing. This suggests that there may be diminishing returns to increasing the spacing gap.

What might the optimal spacing gap be? Answering this question requires a thorough comparison of the effects of different spacing gaps across a wide range of time intervals. In what was probably the most comprehensive study ever to explore this, Cepeda et al. (2008) gave adult learners a flashcard-like web tutorial in which they learned a set of obscure facts (e.g., Libya's flag consists of a single solid color). During the first learning session, participants learned 32 of these facts until they could recall each of them successfully. Then, each participant completed a second learning session in which they were quizzed over each fact (e.g., what country's flag consists of a single solid color?), and then shown the answer (e.g., Libya). Finally, each participant was given a final test over each fact in which they were shown this question again and asked to recall the answer. The spacing gap between the two learning sessions ranged across a half dozen values between zero and 105 days. For example, some participants completed the two learning sessions with a two-day spacing gap, others with a seven-day gap, and others with a 21-day gap. Following the second learning session, each participant completed the final test after a test delay of seven days, 35 days, 70 days, or 350 days. Each participant was randomly assigned to one of 26 unique combinations of spacing gap and test delay.

Figure 3 shows the proportion of facts correctly recalled on the final test as a function of spacing gap and test delay. The key finding from this study is that the optimal spacing gap depends on when the information will be tested in the future. For participants who completed the final test seven days after their final study session, the optimal spacing gap was one day. However, for participants who waited 35 days before taking the final test, the optimal spacing gap was 11 days. For those who completed the final test after 70 days, the best spacing gap was 21 days. In general, the optimal spacing gap equaled 10% - 20% of the test delay. In other words, the longer the test delay, the longer the optimal spacing gap.

This study demonstrates that there is no "one-size-fits-all" approach to using spacing as a means of improving memory retention. Quite simply, a longer spacing gap is not always better. Instead, these findings suggest that in order to pick the optimal timing of study sessions, students and instructors must decide when they expect to need the information. If the goal is to retain information for just a short time, shorter spacing gaps may be ideal. However, if the goal is to achieve retention for much longer periods, spacing gaps of several weeks or months may be best. Indeed, for lifelong preservation of knowledge, spacing gaps of years may well be optimal.

While the study by Cepeda et al. (2008) sought to determine the optimal duration of a spacing gap when learning is limited to only two sessions, numerous studies have addressed a related question: if learners encounter information in three or more sessions, should the spacing gaps be equal? Studies that have explored the effects of different spacing gaps with three or more learning sessions have typically compared two schedules of spacing: (1) a fixed schedule, in which all spacing gaps are identical (e.g., information is studied four times, with a 24-hour spacing gap separating each study session), or (2) an expanding schedule, in which the spacing gap becomes progressively longer (e.g., information is studied once, then again after 30 minutes, then a third time after 24 hours, and a fourth time after one week).

Experiments comparing fixed and expanding schedules have produced equivocal results. Some studies have found that expanding schedules produce better learning than fixed schedules (e.g., Cull, Shaughnessy, & Zechmeister, 1996; Landauer & Bjork, 1978), and others have found that expanding and fixed schedules produce similar levels of learning (e.g., Carpenter & DeLosh, 2005; Cull, 2000; Logan & Balota, 2008; Pyc & Rawson, 2007; for a critical review of this literature, see Balota, Duchek, & Logan, 2007).

Recent evidence suggests that expanding schedules might be better for short-term retention, and fixed schedules might be better for longer-term retention (Karpicke & Roediger, 2007). A comprehensive comparison of various spacing gaps and test delays involving three or more learning sessions has yet to be carried out, and until then it remains an open question whether the optimal spacing gaps for three or more learning sessions are critically dependent upon when the final test takes place.

One finding appears to be reliable, however. Any form of spacing—whether it is fixed or expanding—appears to promote learning. In studies comparing either a fixed or expanding schedule to a massed schedule in which three or more presentations of an item occur back-to-back in immediate succession, it has been consistently demonstrated that either type of spacing schedule produces better learning than a massed schedule (e.g., Carpenter & DeLosh, 2005; Cull, 2000; Rea & Modigliani, 1985).

Thus, when faced with the practical question of when to review information, the present findings suggest that students and teachers do not need to be overly concerned about whether the spacing gaps that separate repeated study sessions are equal or not. The key criterion is that information should be reviewed after a period of time has passed since the initial learning. Particularly if the goal is long-term retention, the findings from Cepeda et al. (2008) suggest that the ideal time to review information may be several weeks or months after it was initially learned.

Pedagogical recommendations and responses to potential challenges

Many researchers have urged teachers and curriculum designers to use spacing as an instructional strategy (e.g., Bahrick, 1979; Bjork, 1979; Dempster, 1987, 1988, 1989; Halpern, 2008; Metcalfe, Kornell, & Son, 2007; Pashler, Rohrer, Cepeda, & Carpenter, 2007; Willingham, 2002). Unfortunately, however, spacing has yet to be systematically implemented in educational curricula (e.g., Cepeda, Vul, Rohrer, Wixted, & Pashler, 2008; Dempster, 1988; Rohrer & Pashler, 2010). One reason for this could be that research on spacing has not produced a clear set of recommendations for how it can be used in everyday instruction. In this section, we describe some specific strategies that can be used by students and educators to capitalize on the advantages of spacing.

The literature reviewed here suggests that in order to promote long-term retention of knowledge, students should receive spaced re-exposure to previously-learned information. Particularly if the goal is long-term retention, it may be beneficial to review this information after a time period of at least several weeks (e.g., Cepeda et al., 2008). This review can take place in a number of ways. First, instructors might incorporate into each lesson a brief review of concepts that were learned several weeks earlier.

Second, homework assignments could be used to re-expose students to important information that they have learned previously. This recommendation may be particularly useful when class time is limited and a review is difficult to fit in to the lesson on any given day. For example, an instructor could intentionally include questions covering information that was learned in class several weeks earlier.

Third, instructors could give exams and quizzes that are cumulative. In addition to re-exposing students to information that they have previously learned, cumulative exams and quizzes provide students with a good reason to review information on their own. These three recommendations are not mutually exclusive, and like any guidelines, they are more likely to produce positive learning outcomes when used in conjunction with one another (for more on pedagogical recommendations involving spacing, see Pashler et al., 2007).

These recommendations may sometimes be difficult to carry out. First, students often seem to be less than enthusiastic about cumulative exams. When the exam is cumulative, students may feel that there is more information that they must study. However, if students are provided with regular reviews of previously-learned information, this information is more likely to remain accessible in memory, reducing the need for them to re-study old information that has already been forgotten.

Second, instructors may be discouraged to find that after several weeks, students have forgotten much of the information that they had previously known. It is commonly the case that students forget a good deal of what they have learned, especially after lengthy time periods (e.g., Carpenter, Pashler, Wixted, & Vul, 2008; Dillon, 2008). Importantly, however, this is not an indication that the instruction was wholly futile. On the contrary, when students are re-exposed to information that they have learned but temporarily cannot recall, they acquire this information much faster than information that is being learned for the first time (e.g., Berger, Hall, & Bahrick, 1999; Ebbinghaus, 1885/1913; Nelson, 1985). Thus, although forgetting is likely to be a necessary consequence of reviewing information after long spacing gaps, re-exposing students to this information on a regular basis will keep it accessible in memory and render it less vulnerable to forgetting over time.

A final challenge that instructors might encounter in implementing spacing into learning curricula is the fact that educational materials appear to discourage this approach. In particular, many textbooks present information in a non-distributed fashion. For instance, although spacing has been known to improve foreign language learning (e.g., Bahrick, Bahrick, Bahrick, & Bahrick, 1993; Bahrick & Phelps, 1987; Bird, 2010; Bloom & Shuell, 1981), in most foreign language textbooks, the vocabulary of each chapter is devoted to a particular topic (e.g., food, clothing), and these words rarely appear in subsequent chapters. Likewise, in most mathematics textbooks, each set of problems is devoted to the most recent lesson. After learning about ratios, for example, students will work one or two dozen ratio problems.

Because textbooks do not typically provide spaced exposure to concepts, in order to ensure that students receive this, instructors may find it necessary to supplement the information from any given lesson with examples from previous lessons. For example, in one rarely-used approach to mathematics learning, each lesson is followed by an interleaved set of examples from many different lessons. Interleaving inherently provides spaced practice, and, no less importantly, it also provides students with an opportunity to choose the appropriate strategy for a given kind of problem, which students need not do when every problem concerns the same procedure or concept (e.g., Rohrer, 2009; Taylor & Rohrer, 2010).

In this review we have highlighted some key findings concerning the types of learning that benefit from spacing, demonstrations of spacing effects in educational settings, and explorations of the ideal spacing gap. We have also attempted to shed some light on how the benefits of spaced practice might be implemented in everyday instruction. We hope that this information can be of value to students and educators who are seeking ways of using spacing to maximize learning.

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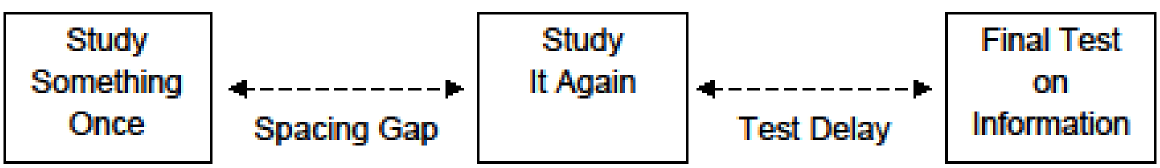

Figure 1*.* Design of a typical study on the spacing effect. Participants experience two learning sessions that are separated by an interval of time referred to here as the spacing gap. After another interval of time called the test delay, participants are given a final test over the information that they encountered in the two learning sessions.

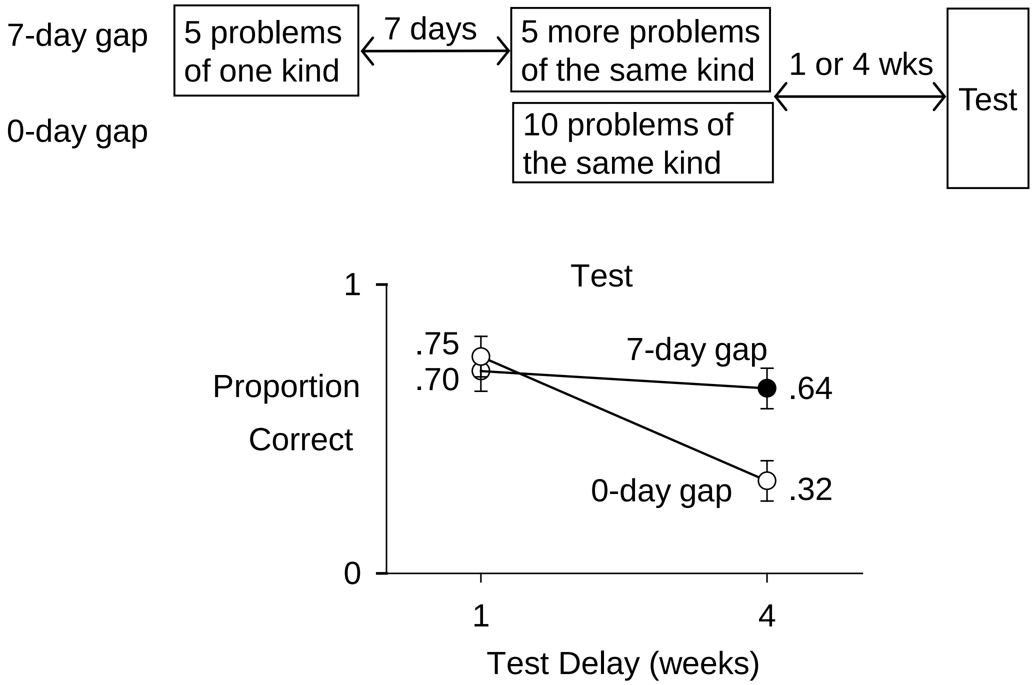

Figure 2. A mathematics spacing experiment. College students observed a tutorial on how to solve an obscure kind of permutation problem before attempting 10 practice problems that were given in a single session (0-day spacing gap) or spaced across two sessions separated by one week (7-day spacing gap) (for full details, see Rohrer & Taylor, 2006). A test with novel problems of the same kind was given one or four weeks later. Spacing had no reliable effect on test scores after a one-week delay but doubled test scores after a four-week delay.

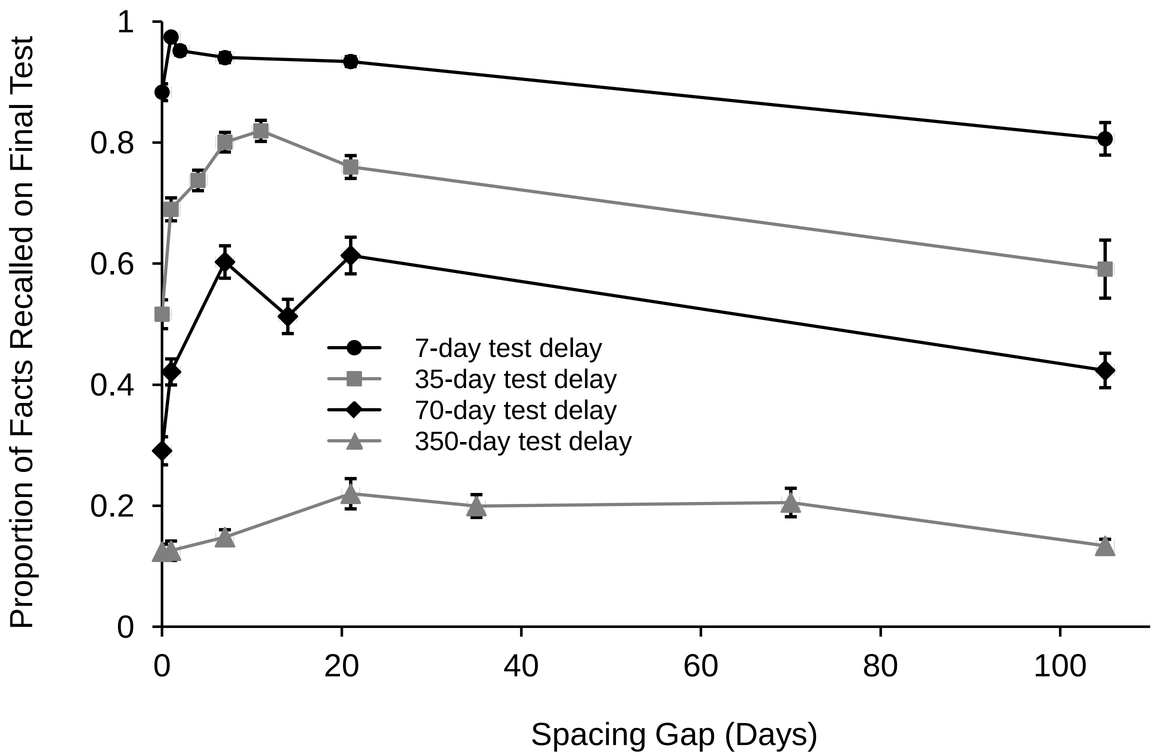

Figure 3. Proportion of facts recalled in the study by Cepeda et al. (2008) as a function of spacing gap (either 0, 1, 2, 4, 7, 11, 14, 21, 35, 70, or 105 days) and test delay (either 7, 35, 70, or 350 days). The spacing gap that produced the highest level of recall was dependent upon the test delay, such that shorter spacing gaps (e.g., one day) were more beneficial for recall after a relatively short test delay (e.g., seven days), and longer spacing gaps (e.g., 21 days) were more beneficial for recall after a longer test delay (e.g., 70 days).