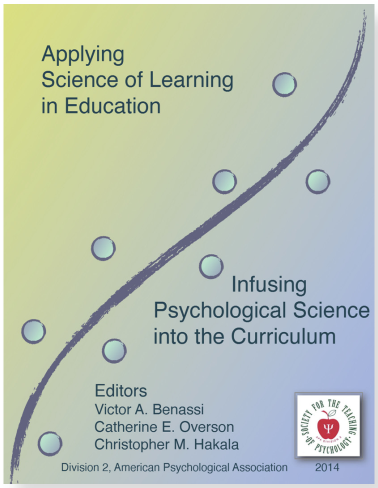

Spacing and Interleaving of Study and Practice

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Overview and Scope of the Chapter

Learning requires repetition. Whether conjugating verbs in a foreign language, applying a mathematical formula, or learning to pitch a softball, a particular concept or skill must be practiced multiple times before it is fully mastered. It seems rather intuitive that learning benefits from repetition, however, what is less intuitive is how these repetitions should be scheduled. When learning a new concept, should students study that concept again immediately? Or should they wait a while and study it again later? A related question concerns how to schedule repetitions of similar concepts within a subject. When students learn about fractions, for example, should they practice one type of fractions problem over and over (e.g., how to add fractions) before moving on to a different type of problem (e.g., how to multiply fractions)? Or, would they learn the information better by practicing both types of problems together?

Students and instructors are faced with these decisions on a daily basis. Research on human cognition has shown that learning can be significantly affected by the way in which repetitions are scheduled. This research can help inform the decisions that students must make concerning when to study information in order to maximize learning. This chapter describes relevant research and offers pedagogical recommendations regarding two specific learning principles—the spacing effect and the interleaving effect.

The Spacing Effect

A number of studies have manipulated the timing of repeated exposures to information and then measured the resulting effects on memory retention. These studies find that learning is better when two or more exposures to information are separated in time (i.e., spaced apart) than when the same number of exposures occurs back-to-back in immediate succession. For example, Dempster (1987) found that students retained a greater number of vocabulary definitions when a given term and definition were repeated approximately every 5 minutes, rather than when the same term and definition were repeated consecutively. The learning advantage for information that is repeated in a "spaced" fashion is commonly referred to as the ***spacing effect***.

The design of a typical study on the spacing effect is illustrated in Figure 1. This design includes: (1) At least two study sessions that involve exposure to the same information, (2) A final test over the information, (3) a period of time, referred to here as the ***spacing gap***, that separates the two study sessions, and (4) Another period of time, referred to here as the ***test delay***, that separates the last study session from the final test. In the most basic experimental designs, the test delay is usually fixed (e.g., 20 minutes), and the spacing gap is manipulated. When the spacing gap is set at zero such that two exposures of the same information occur immediately (i.e., the same vocabulary term is repeated back-to-back), the exposures are said to be ***massed***. When the spacing gap is greater than zero such that the two exposures are separated by some amount of time, the exposures are said to be ***spaced***. The duration of spaced exposures varies across studies and has ranged anywhere from a few seconds (e.g., Carpenter & DeLosh, 2005) to several weeks (Cepeda, Vul, Rohrer, Wixted, & Pashler, 2008). Regardless of the exact value of the spacing gap, spaced repetitions typically yield better learning than massed repetitions.

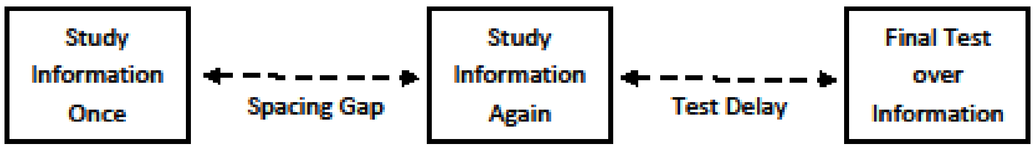

Figure 1. Illustration of a typical experiment on the spacing effect. Students are exposed to information at least twice, with each exposure separated by a spacing gap that can range anywhere from zero (i.e., the same information is repeated back-to-back), all the way to several weeks. Retention on the final test is typically better following a spacing gap greater than zero (i.e., spaced) compared to a spacing gap of zero (i.e., massed).

Sometimes the spacing gap is manipulated across individual items, such that a given term or concept is repeated in massed or spaced fashion (as in the study by Dempster, 1987). Other times, the spacing gap is manipulated across study sessions. For example, students may use flashcards to study each of 30 vocabulary definitions once. After going through the list, students may go back through the list immediately (massed), or they may wait for a period of time (e.g., 30 minutes, one day, etc.) before going back through the list (spaced). This way, there is no immediate repetition of a given item. Rather, the second exposure to a given item will occur after a relatively brief time interval (when the list repetitions are massed) vs. a relatively longer time interval (when the list repetitions are spaced). Under these conditions, spaced study sessions result in better learning than massed study sessions (e.g., Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006). Somewhat related to this, some studies have found that longer spacing gaps produce better learning than shorter spacing gaps (e.g., Kahana & Howard, 2005). This finding is sometimes referred to as the *lag effect*. In this chapter, the term ***spacing effect*** is used to refer to both the advantage of spaced vs. massed exposures, and the advantage of longer vs. shorter spacing gaps.

Research on the Spacing Effect

The spacing effect has been documented in hundreds of published studies over the last century (for review articles, see Cepeda et al., 2006; Delaney, Verkoeijen, & Spirgel, 2010). The majority of these studies have been conducted in the laboratory involving adult participants who demonstrate benefits of spacing over relatively brief time intervals of less than one day. However, other studies demonstrate benefits of spacing in more diverse populations such as young children (e.g., Rea & Modigliani, 1985; Toppino, 1991; Toppino & DiGeorge, 1984) and older adults (e.g., Balota, Duchek, & Paullin, 1989). Of particular interest here are studies that have demonstrated benefits of spacing on long-term learning in authentic educational contexts.

Recent studies conducted in classrooms have revealed promising results for the potential of spacing to enhance student learning in real educational settings. In one recent study, Sobel, Cepeda, and Kapler (2011) taught fifth grade students the definitions for several uncommon English words (e.g., abscond). Students learned these terms and definitions by means of an interactive tutorial that included oral practice, paper-and-pencil activities, and instructor-led demonstrations. Students completed the tutorial twice, with both sessions either occurring on the same day (massed group) or on two separate days separated by one week (spaced group). Five weeks after completing the second tutorial, all students completed a final test over the vocabulary terms. On this test, retention of vocabulary definitions was significantly higher for students who repeated the tutorial after one week (20.8%) than students who repeated the tutorial on the same day (7.5%).

In another study, Carpenter, Pashler, and Cepeda (2009) examined eighth-grade students' retention of information they had learned in their U. S. history course as a function of when they received a review over the information. After completing the course, all students participated in a review session that involved answering questions that were drawn from the last unit of their course (e.g., Who assassinated president Abraham Lincoln?). Students provided their answers on a sheet of paper, and then were given a sheet of paper containing the correct answers to check their accuracy. One group completed this review activity one week after the course ended, and another group completed the review 16 weeks after the course ended. Nine months after completing the review, all students completed a final test assessing their knowledge of the same information. On this test, retention of course content was significantly higher for students who completed the review after 16 weeks (12.2%) compared to one week (8%). After such a lengthy test delay, it is not surprising that substantial forgetting occurred in both of these classroom-based studies. The key finding from these studies is that spacing appeared to reduce the amount of information forgotten over time, resulting in a significantly greater proportion of information retained, even after several months.

In another classroom-based study, Seabrook , Brown, and Solity (2005) demonstrated significant benefits of spacing on first graders' learning of phonics reading skills. During their regularly scheduled classes, all children received a total of six minutes of phonics instruction per day for two weeks. One group (the massed group) received a single session of instruction that lasted six minutes, whereas another group (the spaced group) received three separate instructional sessions on the same day, each lasting two minutes. At the end of two weeks, students who completed the spaced two-minute sessions showed greater improvement in these skills than students who completed the massed six-minute sessions.

Other studies involving adult learners have demonstrated significant benefits of spacing on the learning of educationally-relevant materials. For example, Bird (2010) found that the learning of English grammatical rules, as assessed by a test given 60 days after learning, was enhanced by practicing these rules with a 14-day spacing gap as compared to a three-day spacing gap. Rohrer and Taylor (2006) taught participants to solve a mathematics permutation problem by working through 10 practice problems on the same day (zero-day spacing gap) vs. working on the same 10 problems divided over a spacing gap of seven days (i.e., five problems on one day, and five problems a week later). A final test covering the same type of problems given four weeks later demonstrated significantly greater retention for the group that worked through the problems with the seven-day spacing gap (64%) vs. the zero-day spacing gap (32%).

In another demonstration of the long-term benefits of spacing, Bahrick (1979) taught participants English-Spanish vocabulary through six learning sessions that were administered after spacing gaps of zero days (i.e., all six sessions took place on the same day), one day (i.e., one session per day for six days), or 30 days. A final test given one month after the last learning session revealed the best retention for participants who experienced the 30-day spacing gap. In a follow-up study, the advantage for those who practiced with the 30-day spacing gap was still apparent after eight years (Bahrick & Phelps, 1987).

The studies by Bahrick raise an important question: Are longer spacing gaps always better? A recent study by Cepeda et al. (2008) revealed important information about the optimal spacing gap. In this study, adult participants learned a set of obscure trivia facts via a flashcard-like tutorial that involved answering questions (e.g., What country's flag consists of a single solid color?) and receiving feedback (e.g., Libya). Participants completed two of these learning sessions followed by a final test. Each participant experienced a different combination of spacing gap and test delay, with spacing gaps ranging between zero and 105 days, and test delays ranging between seven and 350 days. Cepeda et al. found that the optimal spacing gap depended on the test delay (see Figure 2), such that shorter spacing gaps tended to produce better retention after relatively short delays, whereas longer spacing gaps tended to produce better retention after longer delays. More specifically, memory retention was best when the spacing gap was about 10-20% of the test delay. Thus, in order to optimize the benefits of spacing, learners should be aware of how long they wish to retain the information, with longer spacing gaps ideal for long-term retention.

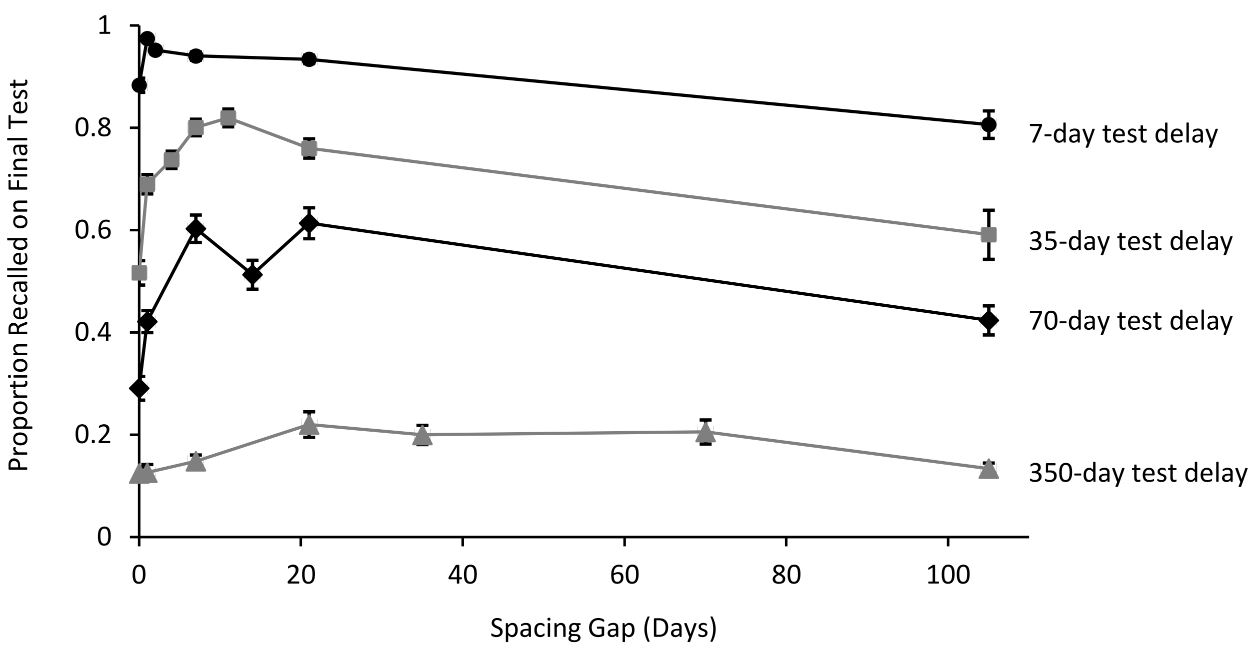

Figure 2. Memory retention of obscure facts from Cepeda et al. (2008). Participants learned these facts through various combinations of spacing gaps (0, 1, 2, 4, 7, 11, 14, 21, 35, 70, or 105 days) and test delays (7, 35, 70, or 350 days). Shorter spacing gaps (e.g., 1 day) were more beneficial for relatively short-term retention (e.g., 7-day test delay), whereas longer spacing gaps (e.g., 21 days) were more beneficial for longer-term retention (e.g., 70 days).

The Interleaving Effect

In any academic subject, students must learn a variety of different subareas. For example, in learning to conjugate verbs in a foreign language, students need to learn present-tense conjugations, as well as past-tense and future-tense conjugations. In geometry, students must learn different formulas for calculating the volume of different types of objects. Just like the decision of how to schedule repetitions of the same information (i.e., spacing vs. massing), students and instructors are also faced with the decision of how to schedule study repetitions of different types of material within a particular subject.

An intuitive approach is to study the same type of material over and over again before moving on to a different type of material. For example, in foreign language instruction, students typically receive extensive practice at conjugating verbs in the present tense before moving on to past-tense or future-tense conjugations. In mathematics learning, students often receive repeated practice at solving one type of problem (e.g., addition of fractions) before moving on to a different type of problem (e.g., subtraction or multiplication of fractions). In this sense, the scheduling of repetitions is said to be ***blocked*** by type of problem, such that one type of problem is repeatedly practiced before moving on to a different type.

An alternative approach is to practice all of the problems in an order that is more random and less predictable. For example, after learning about fractions, students may encounter one problem requiring addition of fractions, followed by a problem requiring subtraction, then a problem requiring multiplication, then another problem requiring subtraction, and so on. In this case, the order of problems is said to be ***interleaved*** because problems of a different type are mixed together rather than separated.

Figure 3 illustrates the design of a typical study on interleaving vs. blocking. Here, students receive the same number of exposures to the material (e.g., three examples each of concepts A, B, and C). The only difference is that blocking involves repeated exposure to one concept at a time, whereas interleaving involves a mixed presentation of all three concepts.

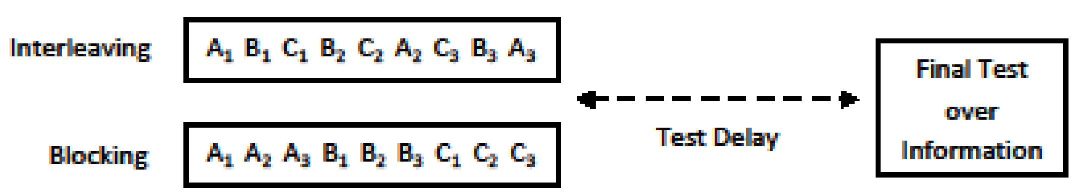

Figure 3. Illustration of a typical experiment on interleaving. Students encounter multiple concepts (A, B, and C) in an order that is either blocked by concept, or interleaved such that a mixture of all of the concepts is presented together. Retention on a final test is typically better following interleaving than blocking.

Studies on this topic typically find that interleaving produces better learning than blocking, a finding referred to here as the ***interleaving effect***. For example, in a study by Rohrer and Taylor (2007), students learned the formulas for calculating the volume of four different types of solid figures—wedges, spherical cones, spheroids, and half cones. All students worked through 16 practice problems and were given feedback on the answer after completing each problem. Problems were either blocked by type of figure (e.g., four problems on wedges, followed by four problems on spherical cones, followed by four problems on spheroids, and four problems on half cones), or interleaved (e.g., the same 16 problems occurred in mixed fashion). One week later, a test given over new problems that required the same formulas revealed significantly greater performance for those students who learned through interleaving (63% accuracy) compared to blocking (20% accuracy).

Research on Interleaving

A number of other studies have demonstrated benefits of interleaving in mathematics learning. In a study by Taylor and Rohrer (2010), fourth grade students were taught a two-step formula for calculating each of four properties of a prism—the number of faces, corners, edges, and angles—based on information provided about the number of base sides. For each problem, students were presented with a question (e.g., A prism with 17 base sides has how many edges?), wrote down their answers in a booklet, and were then shown the correct answer. Due to the complexity of the task, students first completed a partial practice phase (requiring them to solve one step of each problem) consisting of 32 problems (eight of each type). Students in the Blocked Group completed all of the problems of one type before moving on to problems of a different type (e.g., eight face problems, followed by eight corner problems, etc.), whereas students in the Interleaved Group completed the same 32 problems in an order that was intermixed and pseudo-randomized such that each type of problem was fairly evenly balanced across the 32 presentations and no two problems of the same type occurred consecutively. Students then completed a full practice phase (requiring them to solve both steps of each problem) consisting of 12 additional problems (three of each type) arranged in the same blocked vs. interleaved fashion as before. On a final test one day later, students were given four new problems (one of each type), and were required to provide the full solution without receiving feedback. Performance on this test revealed significantly higher accuracy for students who learned the problems through interleaving (77%) compared to blocking (38%).

In another study on mathematics learning, Mayfield and Chase (2002) observed benefits of interleaving on the learning of algebraic rules. Over the course of several sessions, college students with poor mathematics skills learned five algebraic rules through completing worksheets that provided an explanation of the rule, examples, and practice problems. One group of students learned the rules through a procedure akin to blocking, in which each rule was learned and then practiced extensively before moving on to the next rule. Another group learned the same rules through a procedure akin to interleaving, which involved continuous practice of previously-learned skills. For example, after learning two types of skills (e.g., order of operations and multiplying exponents), students practiced a mixture of problems tapping these two skills. A third skill was then introduced (e.g., finding the roots of exponents) and this skill was then added to the practice set along with the two previously-learned skills, such that participants practiced a mixture of problems tapping all three skills. A fourth skill was then added, followed by a mixture of problems tapping all four skills, and so on, until all five skills had been learned and practiced. Although a number of logistical constraints prevented achieving precise control over factors such as the exact timing and amount of exposure to practice problems, the results of this study suggest that an approach based on interleaving appears to be more effective than one based on blocking. An exam given at the end of training that assessed knowledge of all five skills revealed a significant benefit of interleaving (97% correct) over blocking (85% correct).

A different line of research has shown that interleaving can also benefit the learning of categorical concepts. In a study by Kornell and Bjork (2008), adult participants learned to classify paintings by particular artists (e.g., Georges Braque, Judy Hawkins, Bruno Pessani, etc.). Participants were shown several example paintings by each artist, in an order that was either blocked by artist (i.e., several Braque paintings, followed by several Hawkins paintings, followed by several Pessani paintings, etc.), or interleaved such that no two paintings by the same artist occurred consecutively (e.g., Braque, Hawkins, Pessani, etc.). Later on, participants were shown new paintings by the same artists, and their job was to identify which artist had painted each painting. Participants who learned the paintings through interleaving, as compared with blocking, performed significantly better at this task. Similar results were observed in a study by Kang and Pashler (2012) who used similar types of paintings, and interleaving has also been shown to benefit participants' abilities to classify different bird species (e.g., Wahlheim, Dunlosky, & Jacoby, 2011).

A logical question concerns whether the benefits of interleaving are simply due to spacing. As discussed in the previous section, two presentations that are spaced apart in time are learned better than two presentations that occur consecutively. Because of the presence of other items in-between each presentation of a given concept, interleaving naturally involves spacing, so the benefits of interleaving may simply reflect the spacing effect. The benefits of interleaving do not appear to be due solely to spacing, however. Some studies have inserted time delays in-between successive presentations of blocked items to match the time delays that occur during interleaved presentations, and have still observed significant benefits of interleaving over blocking (e.g., Kang & Pashler, 2012; Taylor & Rohrer, 2010).

What might account for the benefits of interleaving, then? It has been proposed that interleaving benefits students' ability to make important discriminations between concepts that are easily confused (e.g., Rohrer, 2012). For example, students may confuse the formula for calculating the volume of one type of geometric figure with the formula for another type of figure. Or, based on similarities in painting styles, they may confuse the artist of one particular painting with the artist of another painting. For materials that are prone to such confusions, interleaving may be beneficial because it allows students the opportunity to notice the key differences between two similar concepts, helping them to make that important distinction later on. Supporting this notion, Rohrer and Taylor (2010) found that interleaving was particularly beneficial for reducing errors in discrimination on the final test. That is, students who learned the prism problems through interleaving (compared to blocking) were much less likely to mistakenly apply the solution for one type of problem (e.g., edges) to another type of problem (e.g., corners). Interleaving thus enhanced the abilities of students to apply the appropriate solution to the problem.

There are some exceptions to the benefits of interleaving. In a recent study by Carpenter and Mueller (2013), native English speakers learned several pronunciation rules in French by seeing and hearing example words that represented these rules. The words were either blocked by rule (e.g., bateau, fardeau, tonneau... mouton, genou, verrou... tandis, verglas, admis) or interleaved such that no two words representing the same rule ever occurred consecutively (e.g., bateau, mouton, tandis… fardeau, genou, verglas… tonneau, verrou, admis). On a later test, participants demonstrated greater proficiency for pronunciation rules that were learned through blocking compared to interleaving. The reason why the usual advantage of interleaving was not observed in this study could be due to the possibility that this type of learning did not require discriminative contrast. Instead of noticing key differences between mathematical formulas or artists' painting styles that are easily confused, learning a series of fairly distinct pronunciation rules may benefit more by noticing the similarities among words that share a given rule (e.g., the sound made by "eau" after listening to bateau, fardea, tonneau, etc.), rather than noticing the differences between words that represent different rules. Thus, it is likely that the utility of interleaving depends on the degree to which the learning task requires noticing of similarities within a category, vs. noticing of differences between categories.

Some research also suggests that blocking may be more effective than interleaving when the learning task is particularly difficult. For example, de Croock and van Merriënboer (2007) presented participants with different types of problems that could occur in a simulated complex distiller system (e.g., pipe leakage, sensory malfunction, etc.), and participants were required to troubleshoot these problems. Participants performed better when problems were presented to them in a way that was blocked by type of malfunction, rather than interleaved such that the type of malfunction was different on each problem.

Thus, although some studies have revealed promising effects of interleaving on the learning of mathematical formulas and visual discriminations, much research remains to be done before we fully understand the boundary conditions of the interleaving effect, particularly with respect to how it may be affected by the complexity of the task and the type of processing required—noticing of similarities vs. noticing of differences. For difficult concepts, one approach that may prove useful is to implement a mixture of blocking and interleaving. For example, it may be better to use blocking during early stages of learning, and then once the concept becomes familiar and students begin to grasp it better, they may transition to interleaving. This hybrid approach has been discussed (e.g., Rohrer, 2012), but has not yet been thoroughly explored in any of the known research on interleaving.

Implementing Spacing and Interleaving in Educational Curricula

There are several practical ways that students and instructors might implement spacing and interleaving in educational practice. Research on the spacing effect suggests that students' long-term retention of information is enhanced by reviewing previously-learned information. In particular, if instructors wish for students to retain the information over the long-term, it may be best to review previously-learned information at periodic time intervals of several weeks (e.g., Cepeda et al., 2008).

One way to accomplish this might be to incorporate into current lectures and class activities brief reviews of previously-learned information. These reviews could also be implemented as homework assignments, which may be particularly advantageous when class time is limited. For example, while learning about dependent-samples t-tests in a statistics course, students could receive a number of practice problems dealing with dependent-samples t-tests, in addition to some problems that cover the earlier-learned concepts of independent-samples t-tests and one-sample t-tests. Such an approach capitalizes on the benefits of spacing by requiring students to revisit previously-learned material. Including different types of (potentially confusable) problems also capitalizes on the benefits of interleaving by providing students with the opportunity to notice key differences in the computational steps required for each of these procedures.

Another way to review previously-learned information is to implement cumulative exams and quizzes. By testing students over information that was learned relatively recently as well as in the more distant past, the exams themselves will serve to re-expose students to previously-learned information. In addition, cumulative assessments will likely have an indirect benefit on student learning by providing students with a good incentive to review the information during their own study time.

Research on interleaving shows that students' retention of mathematics knowledge is significantly enhanced by simply re-arranging the order of practice problems. Thus, instructors may wish to take a number of practice problems dealing with a particular concept (e.g., fractions) and give these to students in an order that is unpredictable (e.g., some problems dealing with addition of fractions, some with multiplication, some with division, etc.), as opposed to an order that is blocked by type of problem (e.g., several addition problems, followed by several subtraction problems, etc.).

These implementations do not come without challenges. One obstacle is that students may be reluctant to use spacing and interleaving because these methods increase the perceived difficulty of learning. Students work more slowly, and make more errors, when working a set of practice problems that is interleaved rather than blocked. For example, in Rohrer and Taylor's (2010) study, students who worked practice problems in blocked fashion performed much better during the practice problems (89% accuracy) than students who worked the same problems in interleaved fashion (60% accuracy). Even though performance on the final test—a more reliable indicator of long-term learning—revealed significant advantages for interleaving over blocking, students may nonetheless be disinclined to use interleaving because of the fact that it makes learning *seem* harder. Some studies have surveyed students on the perceived effectiveness of both methods, and found that students consider blocking to be a more effective strategy, even if their own memory retention favors interleaving (e.g., Kornell & Bjork, 2008). The fact that blocking makes learning easier initially may lead students to favor this approach and be reluctant to implement the more difficult, yet more effective, method of interleaving.

Spacing too may be difficult to implement for the same reason. When reviewing information after several days or weeks, it is natural for students to forget much of what they have learned previously. Experiencing difficulty in remembering previously-learned concepts, and perhaps needing to consult previous chapters or notes, may result in discouragement and the sense that one's previous efforts to learn the information were ineffective. Importantly however, the process of forgetting occurs rapidly, even for well-learned material (e.g., Carpenter, Pashler, Wixted, & Vul, 2008), and should not be taken as a sign that previous learning efforts were in vain. Although it may at first seem that students need to re-learn a great deal of what they have learned before, students can re-learn information faster than they originally learned it (e.g., Berger, Hall, & Bahrick, 1999), and re-visiting this knowledge at periodic time intervals will help inoculate it against further forgetting.

A final obstacle to implementing the principles of spacing and interleaving is the fact that educational materials do not always encourage these approaches. Although spacing improves foreign language vocabulary learning (e.g., Bahrick, Bahrick, Bahrick, & Bahrick, 1993), the vocabulary items in many foreign language textbooks are contained within chapters that are devoted to specific topics (e.g., food, parts of the body), and these items typically do not re-appear in later chapters. Similarly, mathematics textbooks contain chapters that are typically devoted to specific topics, and practice problems usually pertain only to the most recently-learned topic. Given that educational materials do not typically provide spacing and interleaving, instructors may need to modify or supplement the information from these materials in order to ensure that students have the opportunity to use these methods.

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