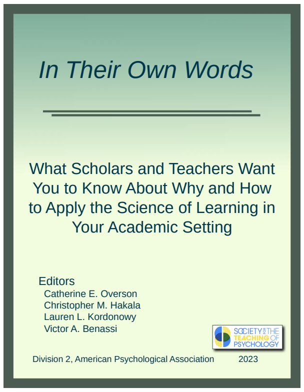

Spaced and Interleaved Mathematics Practice

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Education experts have given considerable advice on how students should best learn, but many of these recommended interventions are ineffective. For instance, schools spend small fortunes on computers for their students despite the lack of evidence for computer-based instruction (Roediger & Pyc, 2012). Other interventions are ostensibly supported by empirical research, but a closer look reveals either flawed research designs or one-off findings that do not replicate (Kirschner & van Merriënboer, 2013). Still other learning interventions have no empirical support and are instead solely based on platitudes and armchair theories (Robinson & Levin, 2019). Fortunately, researchers have identified several effective learning strategies that have consistently proven effective in both the laboratory and the classroom (e.g., Carpenter, 2014; Dunlosky et al., 2014; Pan, 2015).

Two of these are mathematics learning interventions that are the focus of this chapter, and each has produced test benefits in randomized studies. The benefits were found with students between first grade and college, and the learning materials were drawn from a variety of topics, including arithmetic, algebra, and geometry. Studies took place in either the laboratory or classroom, and the delay between practice and test often exceeded several weeks – long enough to be educationally meaningful.

The two interventions are also feasible. Neither requires teacher training, and each allows teachers to present material as they ordinarily would. The interventions can be used in class or at home, with or without computers, and each is free. In this chapter, we describe the interventions, briefly review the evidence for each, and list recommendations on how mathematics teachers can implement the interventions in their courses.

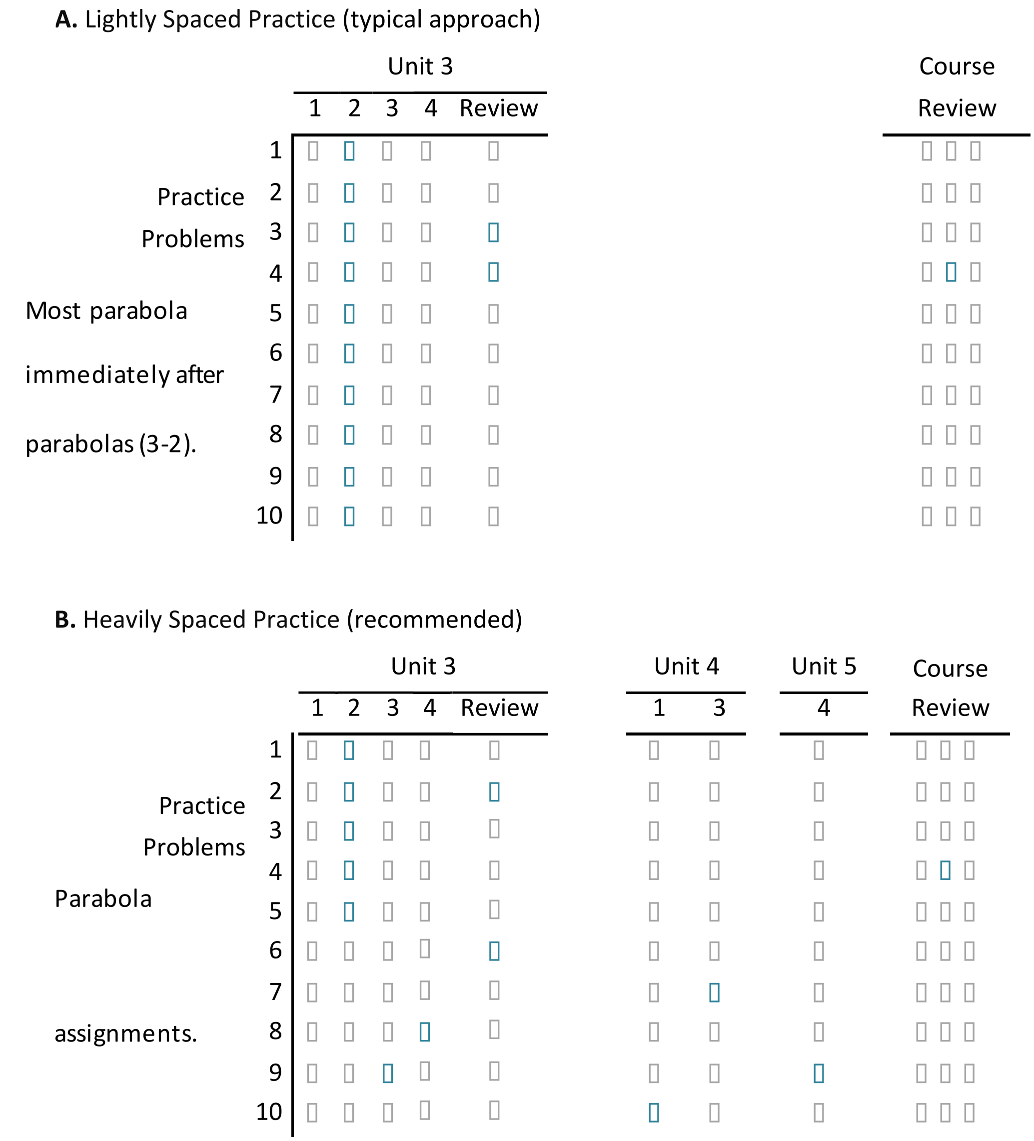
The Interventions: Spaced and Interleaved Practice

Most mathematics textbooks and courses are divided into many short lessons, each followed by a group of practice problems devoted to that lesson – an approach known as *blocked practice*. For instance, a lesson on parabolas is usually followed by a block of parabola problems. Of course, not every problem in the set necessarily takes the same form. Some parabola problems require only an understanding of procedures, whereas other problems might demand a deeper conceptual understanding. Nevertheless, every problem in the assignment relates to a parabola, and students usually realize this before they begin the assignment, often because they have just seen a lesson on parabolas and several worked examples. To be sure, not all assignments are blocked, as most textbooks include periodic review assignments, but even the review assignments usually consist of small blocks of problems. For instance, a chapter review assignment typically begins with several problems relating to the first lesson of the chapter, followed by another small block of problems relating to the second lesson, and so forth. In fact, the majority of problems in most mathematics textbooks can be solved by the same strategy used to solve the immediately preceding problem, as we detail further below. In short, it appears that the majority of mathematics students devote most of their practice effort to working similar kinds of problems in immediate succession.

In an alternative approach that we endorse, a portion of the practice problems in the course are rearranged so that assignments incorporate the two interventions espoused in this chapter. In the first of these interventions, practice problems relating to a particular skill or concept – say, parabolas – should be distributed or *spaced* across many assignments spanning a long period of time. For example, whereas a lesson on parabolas is ordinarily followed by a large block of parabola problems that comprises the majority of the parabola problems in the course, we instead recommend that a *majority* of the parabola problems be spaced (Figure 1).

Figure 1

Spaced Practice

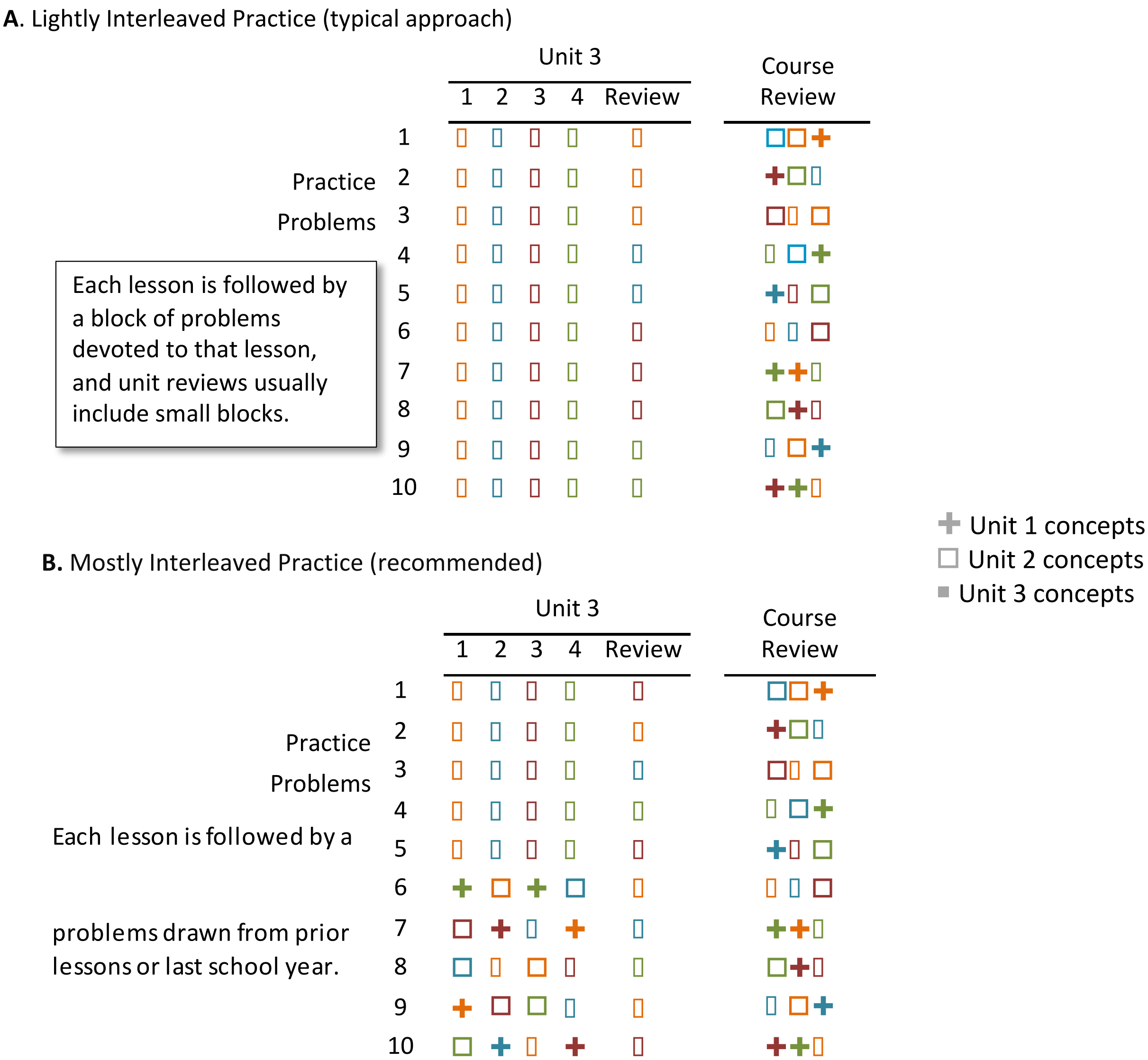


Note. Blue disks represent parabola problems.

By the second intervention recommended here, most of the practice problems in a course should be mixed, or *interleaved,* with different kinds of problems, rather than grouped together into a block of problems requiring the same strategy. For instance, rather than arranging problems so that nearly every circumference problem is preceded by another circumference problem, problems should be arranged so that most of the circumference problems are followed immediately by an unrelated problem, such as a problem about circle area or a problem unrelated to circles. To be clear, at least some blocked practice might be beneficial when students first encounter a new skill or concept, but the data, described in the next section, suggest that a large proportion of problems should be interleaved rather than blocked (Figure 2).

Figure 2

Interleaved Practice



Note. Each symbol represents a unique kind of problem. For example, an orange disk and a blue disk represent two different kinds of problems introduced in Unit 3, whereas an orange square represents yet another kind of problem introduced in a previous unit.

Spaced practice and interleaved practice are similar interventions, but there is a critical distinction between the two. Spaced practice describes the arrangement of a *single* kind of problem (e.g., parabolas), whereas interleaved practice describes the arrangement of *multiple* kinds of problems. In fact, it is possible that problems of a single kind could be spread across time (spaced) without appearing in an assignment that mixes multiple kinds of math problems (not interleaved). That said, the interleaving of practice problems guarantees that problems are spaced as well, meaning that the recommendation to interleave is inherently a recommendation to both space and interleave.

The benefits of interleaving are likely due, at least in part, to spacing, but interleaving provides another benefit that is illustrated by the following problem:

> *A bug crawls 24 cm east and then 7 cm north. How far is the bug from where it started?*

The problem is solved by the Pythagorean Theorem ($24^2 + 7^2 = c^2$, so c = 25 cm), and students must *choose* this strategy (Pythagorean Theorem) before they can *use* the strategy. Yet this choice of strategy is not obvious, because the problem excludes cues such as *triangle* or *hypotenuse*. Throughout much of mathematics, in fact, the choice of an appropriate strategy is more difficult than it might first seem because problems that look alike sometimes require different strategies (Figure 3).

Figure 3

Strategy Choice. Students must discriminate between superficially similar problems.

Problem	Strategy
Arithmetic	
Jo ran ¼ km. Mo ran ½ km farther than Jo ran. How far did Mo run?	Addition
Jo ran ¼ km. Mo ran ½ as far as Jo ran. How far did Mo run?	Multiplication
Algebra	
Solve. $x^2 - x - 1 = 0$	Quadratic Formula
Solve. $x^3 - x = 0$	Factor
Calculus	
$\int x(e + 1)^x \, dx$	Integration by Parts
$\int e(x + 1)^e \, dx$	U-Substitution

Although mathematics students must learn to choose an appropriate strategy, they do not have a chance to practice doing so when every problem in an assignment can be solved with the same strategy. They can instead safely assume that the problem relates to the same skill or concept as the immediately preceding problem. In effect, blocked practice is a kind of scaffolding that has utility, especially when students first encounter a new skill or concept, but blocked practice is not sufficient. Students must ultimately learn to choose a strategy on the basis of the problem itself, just as they must do when they sit for a cumulative exam or other high-stakes test (Higgins, 2019; Rohrer, 2012). In short, interleaved practice provides students with an opportunity to practice doing what they are expected to know.

Evidence for Spaced and Interleaved Mathematics Practice

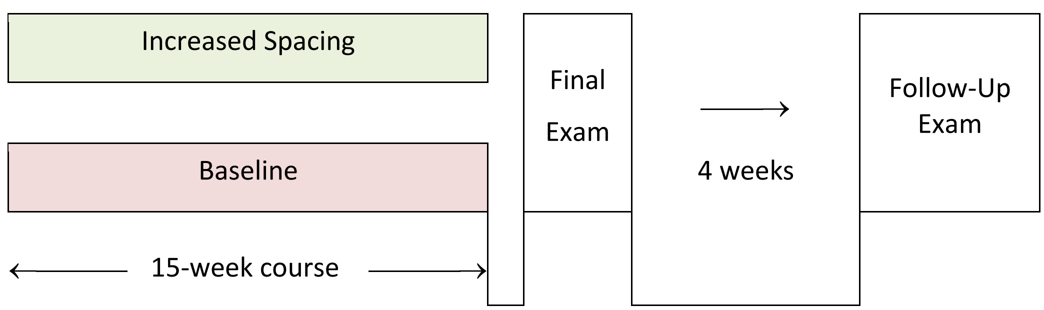
The spacing effect is arguably the largest and most robust effect known to learning scientists, and several randomized studies have shown that spacing improves mathematics learning. The earliest mathematics spacing studies were conducted in the laboratory with college students (e.g., Gay, 1973;

Rohrer & Taylor, 2006, 2007). More recently, the benefits of spacing mathematics were shown in several randomized studies in the classroom, including one with third-grade students learning multiplication and seventh-grade students learning probability (Barzagar Nazari & Ebersbach, 2019), students in a college statistics course (Ebersbach & Barzagar Nazari, 2020), UK students in Year 7 learning about permutations and sets (Emeny et al., 2021), young children learning arithmetic facts (Schutte et al., 2015), and three studies with college mathematics students (Butler et al., 2014; Hopkins et al., 2016; Lyle et al., 2020).

A review of this literature is beyond the scope of this chapter, but for the sake of illustration, we describe the college classroom study by Lyle et al. (2020). This study was fully embedded within a pre-calculus course, and the practice problems related to several of the course objectives (e.g., simplifying radical expressions). Students were randomly assigned to one of two conditions (Figure 4). In the Baseline condition, practice was spaced to a small degree, as is ordinarily the case. For instance, each kind of problem is seen during lectures, practice assignments, and exams, and thus, these exposures are naturally spaced to some degree. The Increased Spacing condition was identical to the Baseline condition with one exception: the practice problems relating to a particular learning objective were distributed across three sessions spaced one week apart. Critically, the students in both groups worked the *same* problems – only the practice schedule varied. The results showed that students who received Increased Spacing, in comparison to the Baseline, scored significantly higher on both the final exam and a follow-up exam given four weeks later.

Figure 4

Classroom Study of Spaced Practice (Lyle et al., 2020)

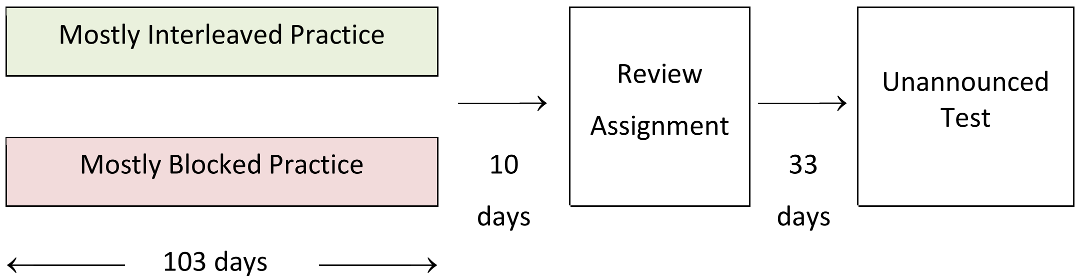


Apart from these mathematics spacing studies, still other randomized studies have found test score benefits of interleaving. These studies include both laboratory experiments with college students (e.g., Foster et al., 2019; Rohrer & Taylor, 2007; Sana et al., 2017) and classroom studies with college students needing remedial mathematics instruction (Mayfield & Chase, 2002), fourth-grade students learning geometry (Taylor & Rohrer, 2010), fifth- and sixth-grade students learning fractions (Rau et al., 2013), seventh-grade students learning elementary algebra (Rohrer et al., 2014, 2015, 2020b), and college students in quantitative science courses such as chemistry (Eglington & Kang, 2017) and physics (Samani & Pan, 2021). Moreover, in many of the studies, a greater dose of interleaving produced particularly large test benefits.

In the study by Rohrer et al. (2020b), for instance, each of 54 seventh-grade classrooms was randomly assigned to one of two groups (Figure 5). One group received worksheets providing mostly blocked practice, and the other received worksheets providing mostly interleaved practice. Every student saw the same practice problems; only their order varied. Students received these assignments periodically for several months, and then every student completed the same (interleaved) review assignment. One month later, students took an unannounced test, and the results showed that the higher dose of interleaved practice produced much higher test scores, 61% vs. 38%.

Figure 5

Classroom Study of Interleaved Practice (Rohrer et al., 2020b)



In short, strong evidence shows that both spaced practice and interleaved practice can dramatically improve test scores in both the laboratory and classroom. Both effects are robust, too, as benefits have been found with a variety of student populations and with diverse kinds of materials. For these reasons, spacing and interleaving have been endorsed by numerous learning scientists (e.g., Bahrick et al, 1993; Bjork & Bjork, 2019; Carpenter, 2014; Dempster, 1988; Dunlosky et al., 2013; Kang, 2016; Pan, 2015; Pashler et al., 2007; Rohrer & Hartwig, 2020; Willingham, 2014).

Apart from improving test scores, spaced and interleaved mathematics practice offer yet another advantage: they help students and teachers more accurately monitor students' learning. For instance, with spaced practice, students revisit a particular kind of practice problem after a period of days or weeks, which can help reveal whether students have truly learned the skill and retained it across time. With interleaved practice, a mix of problems forces students to choose an appropriate strategy for each problem, revealing whether they have learned to recognize when each strategy is appropriate. In contrast, a block of a single kind of problem permits repetition of the same strategy over and over, without revealing whether students have learned to choose appropriate strategies or whether they will retain the skills across time. In fact, blocked practice can create an illusion of mastery (Bjork, 1999; Bjork et al., 2013; Kornell & Bjork, 2008), in which the ease of repeating a strategy throughout a practice session gives the impression that the strategy is well-learned – even when it is not. In other words, blocked practice promotes overconfidence, which is problematic because overconfidence can lead students and teachers to cease practice prematurely and, later, feel surprised and disappointed when the students perform poorly on exams. With spaced and interleaved practice, however, overconfidence is reduced (e.g., Emeny et al., 2021).

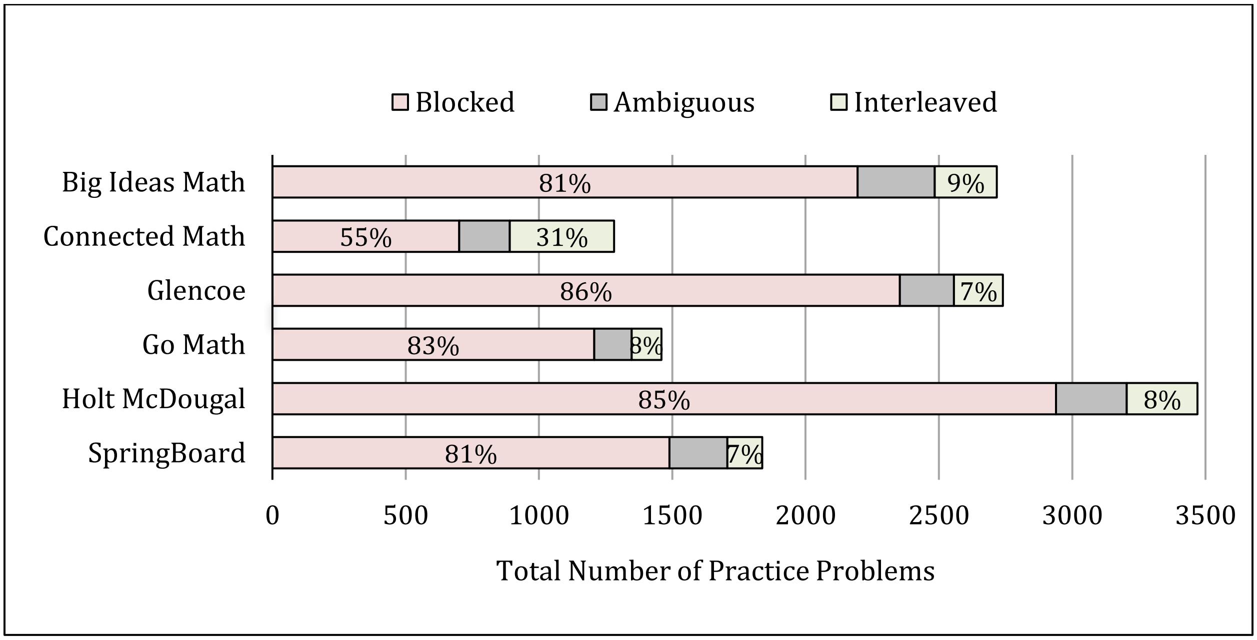
The Prevalence of Blocked Practice

Despite the benefits of spaced and interleaved mathematics practice, blocked practice remains widespread. One reason for the prevalence of blocked practice may be that both students and teachers are often unaware of the benefits of spaced and interleaved math practice. For example, in one recent study, college students were asked to create schedules of math practice they believed would be most effective for learning (Hartwig et al., 2022). The schedules they created predominantly featured blocked practice and incorporated only small amounts of spacing and interleaving. Even when students were asked to choose from several practice schedules with varying amounts of spacing and interleaving, most selected heavily blocked practice. Other surveys of students and teachers have similarly found that blocked practice is often incorrectly perceived to be a superior strategy (e.g., Halamish, 2018; McCabe, 2011; Morehead et al., 2016). Thus, greater awareness of the benefits of spaced and interleaved practice is needed to correct the misconception that practice should be predominantly blocked.

The prevalence of blocked practice can also be seen in mathematics curricula, as shown by a recent evaluation of six widely used seventh-grade U.S. mathematics textbooks (Rohrer et al., 2020a). Raters examined every practice problem in each text and categorized each problem as either blocked (one that can be solved by the same strategy used to solve the preceding problem), interleaved (not blocked), or ambiguous (not easily classified as either blocked or interleaved). Blocked practice predominated each text (Figure 6).

Figure 6

The Scarcity of Interleaved Practice in Six Popular Mathematics Textbooks



Note. Adapted from "The scarcity of interleaved practice in mathematics textbooks," by Rohrer et al, 2020a, *Educational Psychology Review*, *32*, p. 873-883.). Used with permission.

The reason for the prevalence of blocked practice in mathematics textbooks is unclear—perhaps it is simply the default arrangement. Regardless of the reason, the heavy reliance on blocked mathematics practice is not optimal for students' learning. Thus, teachers may need to take steps to increase the amount of spaced and interleaved practice their students receive. We provide guidance below.

Recommendations for Teachers

1. Most of the practice problems in a mathematics course should be spaced and interleaved. In fact, in nearly every study cited here, the students who performed the best were the ones whose practice assignments were arranged so that at least two-thirds of the problems were spaced or interleaved. However, there is no magic proportion because the optimal mixture of spaced, interleaved practice and blocked practice depends on numerous factors, including the nature of the material and the mathematics proficiency of the students. For instance, weaker students might need more blocked practice than do stronger students before confronting interleaved practice.

2. Students should be shown the solution to every practice problem soon after they attempt the problem – perhaps no later than the next school day. We suspect that most teachers already do this, but this kind of feedback is especially important when practice is spaced and interleaved. With blocked practice, students often zip through the assignment by simply repeating the same procedure and are thus less likely to need to see the solutions. With spaced and interleaved practice, however, students more often fail to solve problems, and they cannot learn from such failures unless they receive feedback that provides the correct answer or solution (e.g., Guthrie, 1971; Pashler et al., 2005). In short, a practice problem serves little or no purpose if students do not ultimately understand its solution.
3. Two consecutive interleaved problems need not be entirely unrelated. For instance, a problem solved by the Law of Sines might be followed by one that is solved by the Law of Cosines. This juxtaposition of two fundamentally-distinct, superficially-similar problems might help students identify the critical features of each problem that indicate which strategy is appropriate for each problem (e.g., Dunlosky et al., 2013; Sana et al., 2017). Alternatively, a set of interleaved problems can relate to a single scenario, such as a histogram followed by problems about the mean, median, range, and standard deviation.
4. If the students' textbook and other school-supplied curricula provide mostly blocked practice, teachers can supplement these resources with assignments providing spacing and interleaved practice. For instance, teachers can create their own assignments by choosing one problem from each of a dozen blocked practice assignments in the students' textbook (e.g., a problem from each of 10 different chapters). Teachers also can search the internet for interleaved sets of problems, including practice tests for standardized exams.

Final Remarks

Spaced and interleaved practice are not flashy, but each is strongly supported by empirical research. Both interventions have dramatically boosted test scores in randomized studies in both the laboratory and classroom, and each strategy can be used in nearly any mathematics course. The rationale is straightforward. Whereas blocked practice allows students to infer the relevant concept or strategy needed to solve a problem before they even read the problem, spaced and interleaved practice require that students choose the appropriate strategy for the problem on the basis of the problem itself, just as they must do when given an exam that evaluates multiple skills and concepts. In short, spacing and interleaving give students an opportunity to learn what they are expected to know.

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