22 Enhancing the Quality of Student Learning Using Distributed Practice

Melody Wiseheart, Carolina E. Küpper-Tetzel, Tina Weston, Alice S. N. Kim, Irina V. Kapler, and Vanessa Foot-Seymour

Whether you are an educator or a student, effective time management is critical to achieving success in the formal education system. For educators, the expectation is that a significant amount of curriculum can be covered in a condensed period of time. The goal is to maximize the amount of learning that takes place in the classroom so that students are prepared for the grade level or course that will follow. For students, the expectation is that a range of subject materials will be studied and tested in a short amount of time. This system of learning prioritizes the quantity of knowledge conveyed to students over the quality of students' learning – that is, long-lasting comprehension and retention of the material. In preparation for an upcoming test or exam, teachers and students must decide what material to review and when and how to review it. To maximize the use of limited learning time, it is important to identify learning strategies that will be not only effective but also *efficient* tools for promoting long-term retention of classroom materials.

The field of cognitive psychology offers a wealth of insight on how to enhance knowledge retention. Particularly, researchers have consistently shown the benefit of repetition or reviewing of newly learned information on long-term memory. As explained in the writings of memory researcher Ebbinghaus (1885/1964), "with any considerable number of repetitions a suitable distribution of them over a space of time is decidedly more advantageous than the massing of them at a single time" (p. 89). This phenomenon is called the *distributed practice effect* or *spacing effect*, and it refers to the finding that when reviewing previously learned material, distributing or "spacing" a set amount of study time across sessions leads to better memory performance in the long run than "massing" or cramming the same amount of study time into a single session. A typical research design for investigating the spacing effect consists of two study events and one test event. During the first study event, new material is introduced and learned (sometimes to a criterion); during the second study event, the same material is reviewed; and during the test event, the material is tested (Figure 22.1). The time interval between the first and second study events is referred to as the *interstudy interval*; it can be short/massed (e.g., immediate or a few seconds later) or long/spaced (e.g., minutes, hours, or days later). The time interval between the last study event and the test event is referred to as the *retention interval*; it can also be short (e.g., an immediate test or a test in 5 minutes) or long (e.g., a test a month or year away). Therefore, the distributed practice effect can be studied in both single-session experiments as well as multiday experiments.

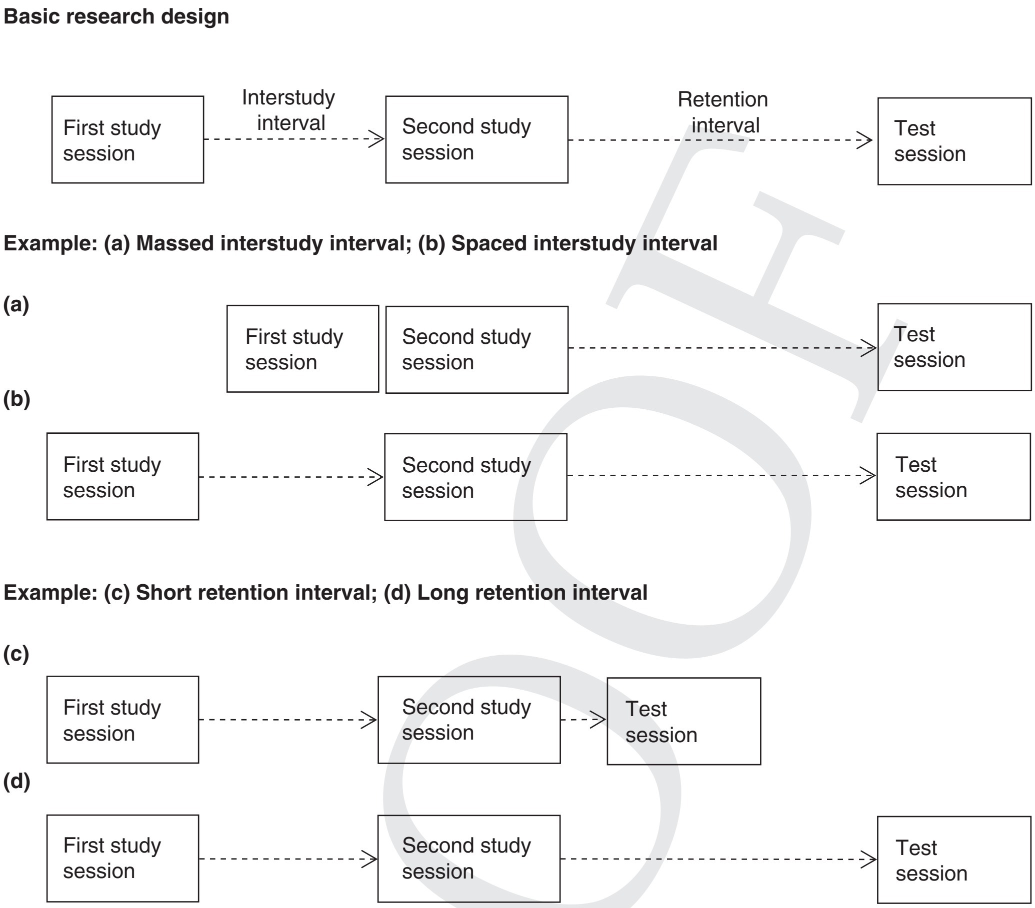

Figure 22.1 *A basic distributed practice research design*

During the first study event, new material is introduced and learned. During the second study event, the material is reviewed. During the test event, individuals are tested on their memory for the material. The time interval that passes between the first and second study events is referred to as the interstudy interval. It is either (a) short/massed or (b) long/spaced. The time interval that passes between the second study event and the test event is referred to as the retention interval. It is either (c) short or (d) long. Note: Some researchers refer to interstudy interval as gap or lag.

In this chapter, we provide a brief historical overview of the distributed practice effect and its theoretical underpinnings. We highlight important studies across a range of different subject matters that demonstrate the versatility of this phenomenon, particularly as it relates to education. We close with a discussion on how teachers and students can incorporate distributed practice into everyday instruction and study, as well as how researchers can address limitations of the current literature.

Historical Studies and Key Findings of the Distributed Practice Effect

Ebbinghaus (1885/1964) conducted the earliest known research documenting distributed practice benefits. He ran a series of experiments on himself to determine how to minimize the amount of time it took for him to relearn a set of material. He found that spacing the study of simple verbal material across several days instead of massing all study into a single day resulted in fewer relearning trials to achieve perfect acquisition. Around the same time, Jost (1897; described in Hovland, 1939) administered a paired-associate task with a fixed number of learning trials, similar to many modern-day distributed practice studies. He also found a distributed practice benefit for simple verbal material. Lashley (1915) subsequently examined skill learning in archery and found that when fewer arrow shots were made per day (40 vs. 20 vs. 5, to a grand total of 320), subjects' final shooting accuracy increased.

Since the work of Ebbinghaus, hundreds of studies have investigated the distributed practice effect, most of which are in the verbal learning domain (e.g., studies that employed words, paired-associates, sentences, or text passages as the study material). Meta-analyses estimate that about 75 percent of 400 plus verbal learning studies in the distributed practice literature show a spacing advantage, about 15 percent show a massing advantage, and the remaining 10 percent of studies show no difference between spacing and massing conditions (Cepeda et al., 2006; Moss, 1995). Generally, reported effect sizes are large; however, as we will discuss in the section "Generalizability of the Distributed Practice Effect," the magnitude of the distributed practice benefit may depend on a variety of factors, such as type of content or skill being reviewed.

Early researchers wondered whether final test performance always benefited from spacing, regardless of the retention interval. Robinson (1921), for example, compared a single massed learning session to two shorter sessions spaced out by 24 hours. He found that spacing only improved performance on the final test when the retention interval was 24 hours. Massed and spaced conditions resulted in identical test performance when the retention interval was only 5 minutes or 20 minutes (average of Tables III and IV in Robinson, 1921, p. 332). This is perhaps the first study showing that a spaced interstudy interval (in this example, 1 day) does not always optimize final test performance. Years later, Glenberg (1976) formally reported that the interstudy interval and retention interval interact, such that the optimal amount of spacing (or time) between the two learning events is different depending on when the final test takes place (see also Cepeda et al., 2008).

Data from Glenberg's (1976) experiments convincingly demonstrate that the effect of interstudy interval is nonmonotonic; that is, increasing the interstudy interval (i.e., amount of time) between study sessions will benefit retention to a point, after which additional increases in interstudy interval will lead to poorer retention (Peterson et al., 1963). The point at which the shift takes place is the optimal interstudy interval for the given retention interval (Glenberg, 1976). Generally speaking, for a test that occurs immediately after learning (i.e., short retention interval), the optimal interstudy interval is massed. Conversely, for a test that occurs further into the future (i.e., a longer retention interval), the optimal interstudy interval is spaced. Glenberg's findings helped to clarify earlier reviews of the distributed practice effect that had not considered retention interval as a factor of interest and therefore had reported incomparable results across some experiments (e.g., Ruch, 1928). Additionally, Glenberg's work paved the way for contemporary mathematical models of the spacing effect that seek to determine the optimal interstudy interval for a host of time scales ranging from seconds to years (Lindsey et al., 2009; Küpper-Tetzel & Erdfelder, 2012).

Thus, memory researchers of the 1960s and 1970s formally defined variables such as interstudy interval and retention interval and demonstrated how these variables (and their interaction) influence the magnitude of the distributed practice benefit (Glenberg, 1979; Hintzman, 1974; Melton, 1970). This work was groundbreaking as it began to clarify the question, "What is the best way to distribute my studying?" (Answer: "Depends on when your test is.")

Explanations of the Distributed Practice Effect

As interest around distributed practice grew in the 1960s, researchers focused their efforts on understanding why the effect occurred and how it could be so remarkably consistent across people and across learning tasks. Two of the major historical theories put forth as explanations of the distributed practice effect – study-phase retrieval and contextual variability – still remain popular today (for a comprehensive review, see Küpper-Tetzel, 2014). Study-phase retrieval theory suggests that greater difficulty retrieving an earlier learning instance of an item leads to greater strengthening of the memory trace for this item during a subsequent learning event (Delaney, Verkoeijen, & Spirgel, 2010; Hintzman & Block, 1973; Murray, 1983; Thios & D'Agostino, 1976). In other words, when retrieval is effortful at the second study event, the difficulty in reaccessing the information improves the likelihood of remembering that item on a final test. However, if too much time has passed between the first and second study events, and the item has been forgotten by the second study events, study-phase retrieval will not take place. The initial memory trace of the item will not be reinforced and final memory for the item will inevitably suffer. This theory suggests that a learner should choose interstudy intervals that are long enough to make retrieval during a subsequent study session effortful, but still successful, meaning that the interstudy will vary depending on the to-be-learned material and the characteristics of the learner. Study-phase retrieval theory does not make strong predictions due to its lack of specificity about the retrieval process (e.g., what are the specific factors that affect the likelihood of successful study-phase retrieval?), and therefore may not be a sufficient explanation for the spacing effect. It also conflicts with research suggesting that the ideal interstudy interval should be determined by the desired length of retention (e.g., Cepeda et al., 2008).

Contextual variability theory suggests that cues such as mood, environmental context, and mental images are encoded alongside items as they are learned

(Estes, 1955; Glenberg, 1979). These cues fluctuate over time and spacing helps to increase cue variability. It is assumed that the probability of successful recall will depend on whether contextual cues at the final test can be used to retrieve previously learned information from memory. The greater the overlap between cues at test and cues stored in memory from each study event, the higher the chances that the target information will be retrieved. When the retention interval is long, greater cue variability during learning increases the probability of retrieval at test; it is assumed that greater cue variability is more likely to occur if practice is spaced out in time. In contrast, when the retention interval is short, relatively less cue variability increases the probability of retrieval at test; it is assumed that less cue variability is more likely to occur if practice is massed. Similarly to study-phase retrieval theory, contextual variability theory lacks specificity (e.g., how can fluctuations in context and cue/trace overlap be measured?) and does not account for the full range of distributed practice effects reported in the literature.

Study-phase retrieval theory and contextual variability theory are not mutually exclusive. Recently, researchers have evaluated the probability of a hybrid account as an explanation of the distributed practice effect – for example, a combination of contextual variability mechanisms with some other mechanism(s), such as study-phase retrieval (Benjamin & Tullis, 2010; Delaney et al., 2010; Lindsey et al., 2009; Mozer et al, 2009; Raaijmakers, 2003). Hybrid accounts acknowledge that no single-mechanism account has been able to account for the wide range of distributed practice findings.

Metacognition and the Distributed Practice Effect

Ironically, although the distributed practice effect is clear across a range of different topics and activities, related research studies in the field of metacognition (i.e., awareness of one's own thinking or behavior) show that the strategy is not used by most learners. On the contrary, most students believe that cramming will improve their memory prior to a test (Kornell, 2009; Kornell & Bjork, 2008; McCabe, 2011; Son & Simon, 2012; Zechmeister & Schaughnessy, 1980). Technically, this belief is correct. Since semesters are the norm in traditional education systems, and tests are often given within weeks of learning a set of material, it is often the case that shorter-term retention is evaluated (days or weeks) rather than longer-term retention (months or years). As we have discussed, when the retention interval is short, a short interstudy intervals will be optimal.

Unfortunately, massing gives the illusion that memory storage is strong and will last for a long time. This belief is incorrect; massing creates more salient memory traces that are prone to forgetting, while spacing produces memory traces that are less salient at the time of initial learning but are more robust to forgetting. (Rohrer & Taylor, 2007, fig. 1B shows that massed memory traces leave memory more quickly; Cepeda et al., 2008, fig. 3a shows that short interstudy interval memory traces are stronger for short retention intervals, whereas long interstudy interval traces are weaker for short retention intervals and are stronger at long retention intervals.) We return to these points in the following sections.

Distributed Practice Schedules

In a more complex distributed practice research design, to-be-learned material is reviewed more than once. Material is introduced during the first study event, reviewed once (second study event), and then reviewed a second time (third study event), before eventually being tested. In this design, the interstudy interval between the first study event and the second study event may be varied, *and* the interstudy interval between the second study event and the third study event may be varied. This research design naturally presents more options for the timing of when material is reviewed; researchers have defined these options as equal, expanding, or contracting learning schedules (Figure 22.2). Studies that have investigated the optimal learning schedule for verbal material across three study events have reported mixed results (e.g., Balota, Duchek, & Logan, 2007; Cull, 2000; Kang et al., 2014). Not surprisingly, the optimal learning schedule is also likely to depend on retention interval. For example, Küpper-Tetzel, Kapler, and Wiseheart (2014) found that contracting learning schedules benefited participants' cued recall memory at shorter retention intervals, and expanding and equal learning schedules benefited participants' cued recall memory at a longer retention interval.

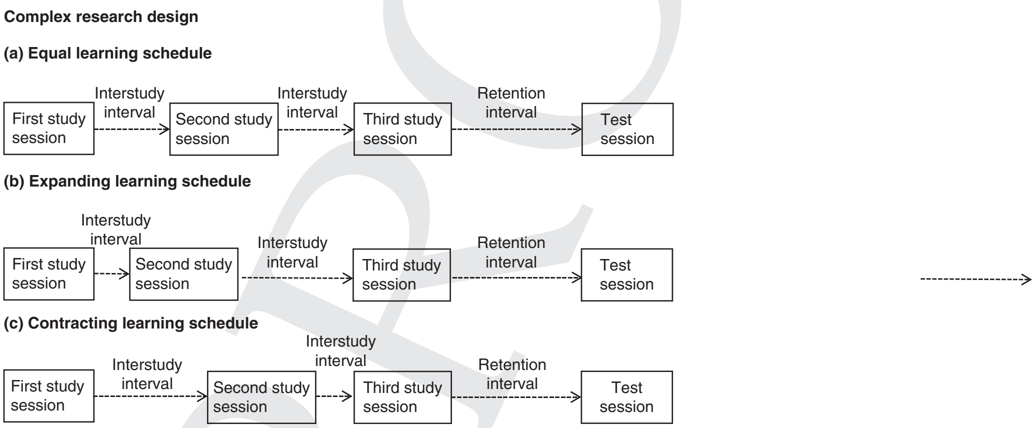

Figure 22.2 *A complex distributed practice research design where three different learning schedules are compared against each other*

In the equal learning schedule (a), the interstudy interval between the first and second study events is the same length as between the second and third study events. In the expanding learning schedule (b), the interstudy interval between the first and second study events is shorter than the interstudy interval between the second and third study events. In the contracting learning schedule (c), the interstudy interval between the first and second study events is longer than the interstudy interval between the second and third study events. Across all three learning schedules, retention interval is fixed, as is total time from first to last study event.

Studies on the distributed practice effect have expanded further to include the concept of "interleaving." Interleaving is the practice of mixing different types of learning activities within a single block of time rather than distributing blocks of the same activity across time. For the sake of conciseness, we do not review any interleaving studies in this chapter. Instead, we refer readers to Chapter XXX in this volume.

Generalizability of the Distributed Practice Effect

The distributed practice effect has been found across different age groups, in addition to different skills and domains. The benefits of distributed practice on knowledge retention have been reported in infants (e.g., Rovee-Collier, Evancio, & Earley, 1995), preschool children (e.g., Toppino, Kasserman, & Mracek, 1991), elementary school children (e.g., Rea & Modigliani, 1987), middle school children (e.g., Carpenter, Pashler, & Cepeda, 2009; Küpper-Tetzel, Erdfelder, & Dickhäuser, 2014), and healthy young and old adults (e.g., Cepeda et al., 2008; Simone, Bell, & Cepeda, 2013). It has been demonstrated in memory-impaired populations, which speaks to its robustness (Balota et al., 2006; Cermak et al., 1996; Green et al., 2014). This large collection of research, which taps into various populations across the life span, suggests that distributed practice can improve how people of all ages learn and retain new information.

To determine the extent to which distributed practice improvements can be generalized, researchers have searched for ways to categorize learning outcomes. Gagné (1977, 1984) outlined five major types of learning outcomes: intellectual skills, verbal information (i.e., verbal learning), cognitive strategies, motor skills, and attitudes. He posited that these categories of learning outcomes have the following characteristics: they are clear in terms of final performance made possible by the learning; they apply to a diverse set of human activities; they require that learning tasks be specific to the category; and, most pertinently, they "differ in the nature of information-processing demands for its learning. Specifically, each kind of outcome requires different (a) substantive type of relevant prior learning, (b) manner of encoding for long-term storage, and (c) requirements for retrieval and transfer of new situations" (Gagné, 1984, p. 378). Research on distributed practice effects has explored three of the five learning categories: verbal information, motor skills, and intellectual skills. Verbal learning happens orally or through writing and consists of facts, conceptual ideas, and other information. Motor skills, on the other hand, are organized sets of actions, such as playing an instrument or throwing a ball. Both simple motor actions and skills executed as part of a complex activity are included in this category. Intellectual skills include higher-order acts of thinking, such as solving mathematical problems or correcting grammar. Outside Gagné's framework, several investigations on distributed practice have been conducted in the context of a fourth learning outcome – social and emotional skills. Social and emotional skills include sensitivity to others' needs and fear responses such as phobias.

Meta-analytic data suggest that the effect size of the distributed practice effect varies across domains, with a large effect size for verbal learning (*d* = 0.85; Cepeda et al., 2006; Moss, 1995) and a medium effect size for motor skills learning (*d* = 0.5; Donovan & Radosevich, 1999; Lee & Genovese, 1988). We estimate a medium effect size for intellectual skills learning (*d* = 0.5; based on Foot, 2016; Kapler, Weston, & Wiseheart, 2015; Vlach & Sandhofer, 2012) and a small effect size for social and emotional skills (*d* = 0.2; based on Korben, 1976; Rowe & Craske, 1998).

Tables 22.1, 22.2, 22.3, and 22.4 provide a list of distributed practice studies across a range of different subjects, organized by three of Gagné's (1977, 1984) five learning outcomes, as well as the social and emotional skills domain. Studies with potential confounds (e.g., different number of relearning trials during session 2 for each experimental condition; different retention intervals for each experimental condition) are included to demonstrate the range of topics that have been investigated, but are marked as confounded. The verbal learning literature is so large that we have chosen to highlight only a small subset of studies in Table 22.1. The other three learning outcomes have much smaller literatures; thus, we have included many (although not all) of these studies in Tables 22.2, 22.3, and 22.4. Because the distributed practice literature is, on the whole, very large, it is not surprising that there is a range of reported effect sizes (weak to strong) and, in some cases, reports of mixed findings.

In the sections that follow, we highlight details for a subset of studies listed in Tables 22.1, 22.2, and 22.3 that had the primary goal of translating the distributed practice effect to educational materials and/or educationally relevant time schedules. Contrary to classic distributed practice studies, many of the studies we review are not formal laboratory studies. The emergence of field and simulated-field studies demonstrates a paradigm shift by the research community toward understanding the distributed practice effect in real-world learning environments. We have emphasized disciplines that, in our opinion, offer empirically sound studies, and these disciplines should provide an understanding of the types of learning that will and will not demonstrate distributed practice benefits.

Verbal Learning

Simple word recall and phonics learning . In a traditional distributed practice study, Seabrook, Brown, and Solity (2005: Experiment 3) taught sounds associated with phonemes (i.e., phonics) to five-year-olds in a classroom setting. Massed practice was compared with a 2 minute interstudy interval and the retention interval was two weeks. Distributed study led to greater phonics improvement than massed study in this sample.

Word and fact learning. Sobel, Cepeda, and Kapler (2011) examined vocabulary learning among 5th grade students, using a typical teaching method employed by elementary school teachers. Students studied and practiced recalling definitions of Graduate Record Examinations (GRE) words and practiced using them in sentences. They compared massed practice to one-week spaced practice and the retention

Table 22.1 *Distributed practice studies of verbal learning*

Subject / Skill	Brief Study Description	Time Scale of Interstudy Interval / Retention Interval	Effect Size~	Number of Study Sessions	Notes	References
Medical Treatment	Dementia patients used spaced retrieval to learn names of friends.	Days / Days and Weeks	Weak	9	* %	Hawley (2002)
	Multiple sclerosis patients learned a paragraph of text and a route on a map.	Mins / Secs and Mins	Weak	3		Goverover et al. (2009)
	A developmental amnesia patient (case study) learned words and paired associates.	1 Day / Days	Strong	2		Green et al. (2014)
	Children diagnosed with speech apraxia completed a speech therapy intervention.	Days / n/a	Mixed	4 or 16	* ^	Webb (2011)
	Children born with a cleft palate practiced speech intelligibility.	Days / n/a	Weak	15 or 104	* ^	Pamplona et al. (2005)
Medical Training	Undergraduate students learned to recognize faces.	Secs / Secs	Mixed	3		Wogalter, Jarrard, & Cayard (1991)
	Medical students studied for a medical licensing exam.	Weeks / Weeks	Strong	Multiple	*	Kerfoot et al. (2011)
History	8th grade students learned US history facts.	Weeks / Months	Strong	2		Carpenter, Pashler, & Cepeda (2009)
Language	5th grade students memorized the definitions of Graduate Record Examinations (GRE) words.	Weeks / Months	Strong	2		Sobel, Cepeda, & Kapler (2011)
	Elementary school children learned basic vocabulary in a classroom field study.	Weeks / Days and Weeks	Weak	Multiple		Goossens et al. (2016)
	6th grade students memorized German–English word pairs.	Days / Months	Strong	2		Küpper-Tetzel, Erdfelder, & Dickhäuser (2014)

5th grade students completed computerized spelling drills.	Days / Weeks	Strong	3		Fishman, Keller, & Atkinson (1968)
Elementary school children practiced reading fluency.	Days / n/a	Weak	12	^	LaRocco (2008)
Kindergarten students practiced reading fluency.	Days / n/a	Weak	15	^	Griffin (2009)
Elementary school children (with and without language impairments) learned verbs.	Days / Secs and 1 Week	Mixed	4		Riches, Tomasello, & Conti-Ramsden (2005)
At-risk kindergarten students learned phonemic awareness.	Days and Weeks / Secs and Weeks	Mixed	24		Ukrainetz, Ross, & Harm (2009)
High school students memorized English–French word pairs.	Days / Secs and Days	Strong	3		Bloom & Shuell (1981)
Elementary school students learned phonics.	Mins / Weeks	Strong	3		Seabrook, Brown, & Solity (2005), Exp. 3
Undergraduates memorized GRE words using flashcards.	Hours and Days / 1 Day	Strong	4		Kornell (2009), Exp. 2
Undergraduates read and comprehended expository narratives.	1 Week / Secs and Days	Strong	2		Rawson & Kintsch (2005)
Undergraduates read and comprehended expository narratives.	Secs and Days and Weeks / Days	Mixed	2		Verkoeijen, Rikers, & Ozsoy (2008)
Undergraduates learned face-name pairs.	Secs / Mins	Strong	3		Carpenter & DeLosh (2005)

% See Creighton, van der Ploeg, and O'Connor (2013) and Oren, Willerton, and Small (2014) for extensive reviews; all but one reviewed study contained a confound.
* Study contains a potential confound.
^ Study did not have a retention interval.
~ Weak indicates not significant or small effect size; strong indicates medium or large effect size and significant or likely to be significant; mixed indicates both weak and strong results.
This table demonstrates the scope of existing research. It is not a complete review.

Table 22.2 *Distributed Practice Studies of Motor Skills*

Subject / Skill	Brief Study Description	Time Scale of Interstudy Interval / Retention Interval	Effect Size~	Number of Study Sessions	Notes	References
Aviation	Undergraduates practiced controlling the altitude of a model airplane using a pulley.	Secs / n/a	Strong	Dozens	* ^	Farr, Dey, & Bloch (1956)
Fine Motor	Undergraduates learned to maintain a ratio of keypresses with each of four keys.	Mins and 1 Day / 1 Day	Strong	3		Shea, Lai, Black, & Park (2000), Exp. 2
Gross Motor	Experienced weightlifters practiced lifts.	Mins / n/a	Strong	1	^	Joy et al. (2013)
	Experienced weightlifters practiced lifts.	Secs / n/a	Strong	1	^	Kreutzer (2014)
	Experienced weightlifters practiced lifts.	Secs / n/a	Weak	1	^	Lawton, Cronin, & Lindsell (2006
	Experienced weightlifters practiced lifts.	Days / Days	Strong	12	^	Oliver (2012)
	Experienced weightlifters practiced lifts.	Secs / n/a	Strong	1	^	Willardson & Burkett (2006a, 2006b)
	Undergraduates adapted to biceps strength training.	Mins and Days / Weeks and months	Weak	1 or 3		Calder & Gabriel (2007)
	Undergraduates learned how to balance on a stabilometer.	Mins or 1 Day / 1 Day	Strong	2		Shea et al. (2000), Exp. 1
Medical Training	Medical students practiced broncoscopy skills.	Mins and Weeks / 1 Month	Weak	3		Bjerrum et al. (2016)
	Medical students practiced endoscopy skills.	Mins and Days / 1 Week	Mixed	3		Verdaasdonk et al. (2007)
	Adult novices practiced laparoscopy skills.	Mins / 5 Mins 1 Week / 2 Weeks	Mixed	3	*	Gallagher, Jordan-Black, & O'Sullivan (2012)
	Medical students practiced laparoscopy skills.	Mins / Mins	Strong	1 or 4		Mackay et al. (2002)

	Medical students practiced laparoscopy skills.	Mins and 1 Week / 2 Weeks and 1 Year	Mixed	1 or 3		Spruit, Band, & Hamming (2015)
	Medical students practiced vascular anastomosis skills.	Weeks and Months / Mins and Months	Weak	4		Mitchell et al. (2011)
	Medical students practiced vascular anastomosis skills.	Mins and 1 Week / Mins and 1 Month	Mixed	4		Moulton et al. (2006)
Military Training	Undergraduates learned command-and-control skills in a simulated naval warfare environment.	Days / Months	Weak	5 or 9	*	Arthur et al. (2007)
	Adults learned a radar position task (similar to radar intercept missions during flight combat).	Mins and Days / 1 Week	Weak	4		Fleishman & Parker (1962)
	Army reserves practiced machine gun assembly and disassembly.	Weeks / Weeks	Weak	1 or 2	*	Schendel & Hagman (1980)
	Army reserves practiced rifle firing skills.	Days / 1 Day	Mixed	10	*	McGuigan & MacCaslin (1955)
Music	Experienced pianists learned a series of short piano compositions.	Mins and Hours and Days / 2 Weeks	Mixed	1 or 2		Rubin-Rabson (1940)
	Novice pianists learning a melodic sequence.	Mins and Hours and 1 Day/ n/a	Mixed	3	^	Simmons (2012)
	Novice undergraduates learning familiar and unfamiliar melodic sequences on a piano.	Mins / Mins	Weak	2		Wiseheart, D'Souza, & Chae (2017)
Sports	Adults learning archery skills.	Days / n/a	Strong	6 to 72	^	Lashley (1915)
	Undergraduates learning to bounce a basketball into the basket from the foul line.	Mins and 1 Day / Mins and Days and Weeks	Mixed	4		Singer (1965)
	Elementary school children learning to dribble a basketball.	Mins / Mins	Strong	2		Christina (1974)
	High school students practicing volleyball serves.	Days / n/a	Weak	6 or 18	^	Fitzgerald (1952)

Table 22.2 (*cont.*)

Subject / Skill	Brief Study Description	Time Scale of Interstudy Interval / Retention Interval	Effect Size~	Number of Study Sessions	Notes	References
	High school students practicing javelin throws.	Days / Months	Weak	34	*	Murphy (1916)
	Undergraduate physical education students learning archery and badminton.	Days / n/a	Mixed	16 or 19	^	Young (1954)
	Undergraduates learning to swim.	Days / n/a	Weak	Variable (5+)	* ^	Scott (1954)
	Undergraduate physical education students learning to juggle.	Days / n/a	Strong	Variable (6+)	^	Knapp & Dixon (1950)
	Novice undergraduates practicing putting skills.	Mins and Days / Days and Weeks	Strong	4		Dail & R. Christina (2004)
	Novice high school students practicing putting skills.	Mins / Days	Weak	12		Lynch (1971)
	Novice undergraduates practicing billiards set shots.	Days / 1 Year	Strong	9		Lawrence (1949); Miller (1948)
	Undergraduates learning how to dribble a soccer ball.	Days and Weeks / Days and 1 Month	Strong	3		Murphree (1971)
	Undergraduates learning gymnastics skills.	Mins / n/a	Mixed	10	^	Kleinman (1976)
Vocation	High school students learning typing skills.	Days / n/a	Weak	9	^	Dritsas (1950)
	High school students learning welding skills.	Days / 1 Day	Strong	7 to 20		Drake (1981; 1987)
	Postal workers learning keyboard skills on mail sorting machines.	Hours / Months	Weak	60		Baddeley & Longman (1978)
	Utility employees memorizing computer shortcut keys.	Mins and 1 Day / 1 Week	Strong	4		Rogers (2004)

* Study contains a potential confound.

^ Study did not have a retention interval.

~ Weak indicates not significant or small effect size; strong indicates medium or large effect size and significant or likely to be significant; mixed indicates both weak and strong results.

Table 22.3 *Distributed practice studies of intellectual skills*

Subject / Skill	Brief Study Description	Time Scale of Interstudy Interval / Retention Interval	Effect Size~	Number of Study Sessions	Notes	References
Aviation	Aviation students interpreted noisy or distorted air traffic communications between pilots and controllers.	Days / 2 Weeks	Weak	2 to 16		Tobias (1976), Exp. 2
Language	Undergraduates corrected verb errors in text passages.	Days / Weeks and Months	Strong	5		Bird (2010)
Mathematics	Middle school students studied math units.	Weeks / Days	Strong	Multiple	*	Wineland & Stephens (1995)
	8th grade students studied mathematics.	Days / Weeks	Weak	Multiple	*	Liang (1970)
	8th grade students studied mathematics.	Days / Months	Mixed	Multiple	*	Weaver (1976)
	High school students solved plane geometry problems.	Days / Secs and Weeks	Strong	7	*	Yazdani & Zebrowski (2006)
	High school students learned algebra rules.	Days / Months	Weak	Multiple	*	Urwiller (1971)
	Undergraduates solved precalculus problems.	Days / Days	Weak	Multiple	*	Revak (1997)
	Undergraduates learned statistics.	Day / Days	Strong	4	*	Smith & Rothkopf (1984)
	Undergraduates learned statistics.	Secs and Weeks / Months	Strong	Multiple	*	Budé et al. (2011)
	Undergraduates used mathematical reasoning to solve a water displacement problem.	Mins / Mins and 1 Day	Weak	8		Hunt (1969)
	Undergraduates used mathematical reasoning to solve a water displacement problem.	Mins / Mins	Weak	9		Scheel (2007)
	Undergraduates learned algebra rules.	Days / Weeks	Mixed	4	*	Mayfield & Chase (2002); Kim (2003)

Table 22.3 (*cont.*)

Subject / Skill	Brief Study Description	Time Scale of Interstudy Interval / Retention Interval	Effect Size~	Number of Study Sessions	Notes	References
	Undergraduates solved permutation problems.	1 Week / Weeks	Strong	2		Rohrer & Taylor (2006), Exp. 1
	Undergraduates solved permutation problems.	1 Week / 1 Week	Strong	2		Rohrer & Taylor (2007), Exp. 1
Media Literacy	Elementary school children learned to judge the credibility of a series of websites.	1 Day and 1 Week / Weeks	Strong	3		Foot (2016)
Science	Elementary school children learned biology facts about food chains and reasoning about food chain consequences.	Days / 1 Week	Strong	4		Gluckman, Vlach, & Sandhofer (2014); Vlach & Sandhofer (2012)
	Middle school students learned biology concepts.	Days / Days and Weeks	Strong	Multiple		Reynolds & Glaser (1964), Exp. 1
	High school students learned physics concepts.	Days / Weeks	Strong	Multiple	*	Grote (1995)
	Undergraduates learned astronomy concepts.	Mins / Secs	Strong	3		Lu (1978)
	Undergraduates learned meteorology facts and applied concepts.	Days / Months	Strong	2		Kapler, Weston, & Wiseheart (2015)
Vocational Training	Adults enrolled in labor education classes practiced computer skills, issues in collective bargaining and handling grievances, union leadership, and commonsense economics.	Days and Weeks / Months	Mixed	6	*	Hertenstein (2000)
	Bank employees learned effective sales techniques.	Days / Weeks	Strong	6	*	Kauffeld & Lehmann-Willenbrock (2010)

* Study contains a potential confound.

~ Weak indicates not significant or small effect size; strong indicates medium or large effect size and significant or likely to be significant; mixed indicates both weak and strong results.

Table 22.4 *Distributed Practice Studies of Social and Emotional Skills*

Subject / Skill	Brief Study Description	Time Scale of Interstudy Interval / Retention Interval	Effect Size~	Number of Study Sessions	Notes	References
Social & Emotional Training	Elementary school children learned emotional coping skills.	Days / n/a	Weak	12	^	Tran (2007)
	Undergraduates learned assertiveness skills.	Weeks / Weeks and Months	Weak	1 or 6		El-Shamy (1976); Korben (1976)
	Undergraduates with arachnophobia completing therapy for extinction of a fear response to spiders.	Mins / Weeks	Strong	1		Rowe & Craske (1998)
	Adult participants enrolled in sensitivity training.	Mins or Days / Months	Weak	1 or dozens		Bare & Mitchell (1972)

^ Study did not have a retention interval.

~ Weak indicates not significant or small effect size; strong indicates medium or large effect size and significant or likely to be significant; mixed indicates both weak and strong results.

interval was five weeks. Students in the spaced condition recalled almost triple the number of definitions on the final test. Using similar stimuli, Kornell (2009) asked undergraduate students to learn GRE words using digital flashcards in an online study. In the spaced condition, participants studied words in a single large stack of twenty cards and the entire stack was presented in the same order four consecutive times. In the massed condition, participants studied the same twenty words in four small stacks of five cards each. Stack #1 was presented four consecutive times, stack #2 was presented four consecutive times, and so forth for all four stacks. Participants were tested for their memory of the words after a median retention interval of 24 hours (range: 17–41 hours). Recall of the word meanings on the final test was, on average, 13 percent higher for words learned in the spaced condition.

In a classroom study, Carpenter, Pashler, and Cepeda (2009) tested 8th grade students on their knowledge of US history facts. After their regularly scheduled exam for the class, students completed delayed relearning of material at interstudy intervals of either one week or sixteen weeks. When tested nine months later, students who had relearned at the sixteen-week interval demonstrated better performance.

Goossens and colleagues (2016) ran field experiments in schools comparing long (two-week) versus short (one-week) interstudy intervals for 2nd, 3rd, 4th, and 6th grade students learning vocabulary words with retention intervals from one to eleven weeks (retention interval varied by age group). Contrary to the evidence presented thus far, the researchers found no systematic differences between the interstudy interval conditions and final memory performance using two different types of tests (cued recall and multiple choice). When they found a difference, it was in the opposite direction, with shorter interstudy intervals outperforming longer ones. However, in the light of previous studies that have revealed a systematic relationship between interstudy interval and retention interval, it is possible that the shorter interstudy interval was better suited for the given retention interval. In addition, field studies like this one introduce higher levels of environmental noise, which can increase error variance in the data and decrease chances of finding an experimental effect.

Second-language learning. Bloom and Shuell (1981) studied vocabulary learning in high school students memorizing English–French vocabulary as part of their regular classwork. Learning took place using multiple-choice, fill in the blank, and cued recall tests. Massed practice and a one-day interstudy interval were compared, and retention intervals of 0 minutes and four days were included. Groups performed equally at the immediate test, and the spaced group showed better performance four days later.

Küpper-Tetzel, Erdfelder, and Dickhäuser (2014) asked 6th grade students in a German school to restudy German–English vocabulary either immediately (massed condition), one day later, or ten days later (two spaced conditions with different interstudy intervals). Final memory tests were given after one week or thirty-five days. In line with previous findings (e.g., Cepeda et al., 2008; Glenberg, 1976), results showed that the optimal interstudy interval for a test one week later was one day, whereas students tested one month later benefited from an interstudy interval of up to ten days.

Text comprehension. Rawson and Kintsch (2005) investigated whether distributed practice aids comprehension of text narratives. Participants read a 2,000-word *Scientific American* excerpt once, twice in a massed fashion, or twice with one week between sessions. They were tested for their comprehension of the passage immediately after the second study session or after a retention interval of two days. Again, the optimal rereading interval depended on the retention interval; massed rereading was best for the immediate test group whereas spaced rereading was best for the delayed test group. Verkoeijen, Rikers, and Ozsoy (2008) replicated the results of this study using three interstudy intervals (massed, four days, and three and a half weeks) and a single two-day retention interval. In the context of their study design, the optimal interstudy interval was four days.

Motor Skills Learning

Sports. Distributed practice has been applied to training protocols in a number of different sports, including golf, basketball, and soccer. For example, Dail and Christina (2004) examined novice golfers (young adults) practicing their putting skills. Massed practice was compared to a one-day interstudy interval, and the golfers' putting performance was assessed following one-, seven-, and twenty-eight-day retention intervals. Distributed practice resulted in better acquisition of golf putting skills as well as improved retention of these skills.

Christina (1974) investigated basketball dribbling in 4th grade students, with dribbling speed as a dependent variable. Massed practice was compared to a 12 minute interstudy interval in which other skills were practiced. The design of this study had additional complexities; overlapping the distributed practice intervention, both massed and spaced groups received distributed practice at several-day interstudy intervals (i.e., several practice sessions occurred during Tuesday and Thursday physical education class sessions). Still, after a formal five-day retention interval, the distributed practice group dribbled faster than the massed group.

Murphree (1971) examined ability to dribble a soccer ball in undergraduates without soccer experience. One group received three consecutive days of practice, a second group received six sessions over three weeks, plus a 20 second rest between trials, and a third group received six sessions over three weeks, plus a 5 minute rest between trials. There was a no practice control group. Retention intervals of several days (exact number not specified) and one month were used. Increasingly spaced groups showed larger gains during skill acquisition. The 5 minute interstudy interval produced the highest scores after each retention interval. There was no evidence of forgetting during the one-month retention interval.

Vocation. Two studies have been conducted examining the effects of distributed practice on welding skills (Drake, 1981, 1987). In both studies, a large number of practice sessions were given, with 5 hours' total training time at welding skills in all conditions. Giving a larger number of shorter training sessions, a form of distributed practice, resulted in higher-quality welding.

Surgical skills. Several researchers have investigated whether distributed practice helps future doctors improve their surgical skills. Bjerrum and colleagues (2016) examined bronchoscopy training using massed practice or a one-week interstudy interval, and a one-month retention interval. Using five different measures of quality of bronchoscope usage, no differences were found between massed and spaced groups.

Verdaasdonk and colleagues (2007) examined endoscopic skills using 15 minute and one-day interstudy intervals, and a one-week retention interval. The spaced group completed tasks faster but no spacing benefit in accuracy was observed. Surgical skills studies show that there are limitations to motor skills benefits from distributed practice. It might be that complex motor skills are less likely to show a distributed practice benefit, while basic motor skills (e.g., repetitive hand movements) are more likely show a benefit.

Intellectual Skills

Mathematics. Rohrer and Taylor (2006) examined permutation problem-solving (sometimes known as transformations in the education domain) in a group of undergraduates, using massed practice and a one-week interstudy interval, and one- and four-week retention intervals. Massed and spaced groups performed equally well at the one-week retention interval, however, the spaced group performed twice as well as the massed group at the four-week retention interval. Rohrer and Taylor (2007) performed a similar study, with less practice per learning session, and found a spacing benefit at the one-week retention interval.

Science. In two studies, 1st and 2nd grade children learned basic biology information using massed versus spaced learning schedules (Gluckman, Vlach, & Sandhofer, 2014; Vlach & Sandhofer, 2012). Children memorized facts about food chains as well how to generalize consequences of disruptions to the food chain. The researchers used interstudy intervals of zero days and one day, and a retention interval of one week. Both massed and spaced lessons benefited memory for facts, with a larger increase in recall for spaced learning. However, only spaced learning resulted in generalization skill improvements. A review of category learning by Vlach (2014) suggests that distributed practice helps infants and preschool aged children to generalize to novel exemplars of a category.

Reynolds and Glaser (1964) examined learning of biology concepts (via computer instruction and testing) in middle school classrooms. In their second experiment, massed and one-day interstudy intervals were compared (intervals estimated, as not explicitly stated by the authors), and retention intervals of ten days and thirty-one days were used. Distributed practice benefited final test performance at both retention intervals.

Lu (1978) taught undergraduates astronomy facts using audio lectures, using either massed learning one concept at a time, or distributed learning in which concepts were repeated throughout the lecture. In the spaced group, a specific interstudy interval was not used. Rather, concepts were repeated and related to new content that was presented in later parts of the lecture. Spaced learning resulted in higher test scores immediately following the lecture.

Kapler and colleagues (2015) presented a lecture on meteorology to a group of undergraduates in a simulated classroom study. Students completed a comprehension test immediately after the lecture to ensure learning had taken place. After interstudy intervals of either one day or eight days, students reviewed the content of the lecture in an online quiz containing both short answer questions and equivalent multiple-choice questions (to ensure relearning had taken place). After a retention interval of thirty-five days, students were tested for their fact knowledge as well as their ability to apply learned information to solve a series of novel problems. Students in the spaced group outperformed students in the massed group on both factual knowledge and application skills, though the effect size was smaller for the latter.

Literacy. Foot (2016) taught 4th through 6th grade students a set of criteria for evaluating the credibility of a website (i.e., media literacy). Credibility lessons were presented on three consecutive days or one lesson per week. After a thirty-five-day retention interval, students in the spaced group recalled more of the criteria and were better able to explain their credibility rating of a novel website compared to students in the massed group.

Bird (2010) taught undergraduate students with intermediate English language proficiency to correctly use verb tenses, with interstudy intervals of three days and fourteen days, and retention intervals of seven days and sixty days. After the seven-day retention interval, both interstudy interval conditions performed equally well (both groups improved in comparison to pretest). After the sixty-day retention interval, students in the fourteen-day condition demonstrated better language reasoning skills than students in three-day interstudy interval condition, indicating a distributed practice benefit for long-term retention.

Summary of Findings

The distributed practice effect appears to be most beneficial for mastering fact learning (e.g., word recall, vocabulary, second-language learning, text comprehension). Although rote memory of words and facts may sound like a shallow type of learning, many disciplines require good foundational knowledge before higher-order thinking skills enter the learning process (e.g., medicine, engineering, law).

Motor skills also benefit from distributed practice, such as in sports training and basic motor training. Unlike verbal learning studies, motor skills studies typically employ several practice sessions, not just the two sessions (basic research design) or even three sessions (complex research design) that characterize the majority of the literature. Motor skills learning is not simply defined by a single correct or incorrect answer; rather outcome measures such as timing, balance, and coordination are uniquely measured and reported. It appears that less forgetting takes place between study sessions during motor practice (e.g., Murphree, 1971; Wiseheart et al., 2017), which may have important implications for theory development of the distributed practice effect.

Evidence for the distributed practice effect in the domain of intellectual skills suggests that this strategy may be applied to higher-level thinking abilities, although the effect might not be as strong. The broad nature of this domain makes generalizations from the data more difficult. It is a challenge for researchers to define what exactly is meant by terms such as conceptual learning, intellectual skills, and critical thinking skills. Moreover, assessing this type of learning is difficult when, like motor learning, there is typically no "correct" answer. Despite these complications, research in this area may contribute to theory development. For example, in the study by Kapler and colleagues (2015), distributed practice improved participants' application skills not only for items that were reviewed at the second study session but also for items that were *not reviewed* at the second study session. This outcome suggests that when learning is not single-fact–based but rather unit- or concept-based (i.e., holistic), distributed practice may have effects on the entire learning experience. Reviewing one concept may implicitly prompt the learner to think of other (nonreviewed) concepts, thereby strengthening memory for all of the information.

Recommendations for Integrating Distributed Practice into Classroom Instruction

As our review of the literature demonstrates, researchers have put great effort into translating distributed practice from the lab into real (or simulated) classrooms and/or using real curricula (e.g., Foot, 2016; Kapler et al., 2015). Generally, the results are positive, which is impressive considering the added variability and complexities of real-world learning (e.g., students missing classes, student distraction, preknowledge of curriculum material, etc.; but see Goossens et al., 2016). The field is at a point where preliminary recommendations can be made to educators and students about how and when to integrate distributed practice into classroom learning. These recommendations may challenge traditional curriculum structure, requiring educators to put more emphasis on integration or restructuring of material rather than simply covering a quantity of information.

Distributed practice is appealing for integration into classroom instruction due to its beneficial effects on learning, reliability across participants and time scales, as well as its versatile potential for implementation. Table 22.5 lists a number of suggestions for implementing a distributed practice strategy into real-world classroom instruction. From the educator's point of view, teachers may choose to space out homework practice (Laing & Peterson, 1973; Peterson, 1971), to administer weekly review quizzes and/or cumulative tests, or choose textbooks that include opportunities for distributed practice (e.g., for a review, see Hood & Ivie, 2003; see also Baldree, 2003; Harden & Stamper, 1999; cf. Johnson & Smith, 1987; Klingele & Reed, 1983; Saxon, 1982). From the student's point of view, learners may choose to

Table 22.5 *Suggestions for implementing distributed practice into classroom instruction*

Teaching Tool	Implementation Techniques
Homework	Students complete at least one practice item from the previous class/week in the homework assigned for the current class/week.
Weekly quizzes	In-class (or online) quizzes that cover material from the previous class/week. Quizzes can be graded for accuracy or simply for completion.
Cumulative exams	Final assessments that cover entire contents of a course. This approach works well in combination with weekly quizzes so that the amount of to-be-learned material is not overwhelming.
Textbooks	Books, articles, and other reference materials that use a distributed practice or interleaving approach.
Technology	Apps, games, and study reminders that integrate distributed practice in entertaining (and portable) ways.

allocate their study time in more efficient ways. They may download games and apps or set study reminders on their electronic devices that maximize learning, even while they are on the go from home to school. We are aware of a number of smartphone apps (e.g., Eidetic, Memrise) that use distributed practice (and also adjust number of learning trials throughout the learning process) to help the learner maximize their performance (e.g., flashcards for the verbal GRE; flashcards for second-language learning). By applying a distributed learning approach, students will be forced to rethink conventional study habits. Study habits that are fluid and that involve little mental effort generally do not support long-term maintenance of knowledge. Rather, when acquisition is made slower or more difficult, as it is with distributed practice, long-term retention is supported. Researchers have termed this type of learning "desirably difficult" (Bjork & Bjork, 2011).

Optimal interstudy intervals for classroom learning depend mostly on how long information needs to be retained, and there is no definitive answer to this question. As study-phase retrieval theory suggests, difficult-to-learn information should be reviewed at shorter time intervals to ensure it is not completely forgotten at review. Yet assuming a desire for long-term retention, contextual variability theory suggests that information should be reviewed at an interval spaced far enough in time that contextual cues in the learning environment have a chance to vary. This review schedule will increase the likelihood that contextual cues at study and test will match, thereby aiding final retrieval. We recommend that study sessions be spaced widely (e.g., across days or weeks) so that the chances of long-term retention are maximized.

A Paradigm Shift in Pedagogical Practices

Although we can make predictions about what information will benefit from distributed practice and at what learning schedules, and we can make recommendations for how to implement spacing into everyday practice, the strategy can only fully be integrated into real educational contexts if educators and policy advisors seriously rethink traditional pedagogical practices. As Vash (1989) writes, "education policy setters know perfectly well [distributed practice] works better; they don't care. It isn't tidy. It doesn't let teachers teach a unit and dust off their hands quickly with a nice sense of 'Well, *that's* done'" (p. 1547). Vash alludes to the fact that many teachers are accustomed to covering topics in chunks, only once per semester, and giving noncomprehensive tests. Teachers are constrained by time and have a lot of curriculum to cover within a narrow time frame. Given these pressures, a unit-by-unit teaching approach might appear to be the best (and perhaps only) option. As discussed at the outset of the chapter, this type of teaching prioritizes the quantity of the content covered over integration of students' knowledge throughout their educational experience. Distributed practice is a strategy that, if used effectively, can vastly improve the quality of student learning and at no (or very little) additional time cost.

Limitations and Directions for Future Research

The distributed practice effect has been studied exhaustively in the laboratory. Although many of these lab studies have involved rigorous experimental methods, others contain confounds in experimental design or analysis problems that preclude interpretation of findings. For example, it is critical that retention interval is controlled across all interstudy interval conditions, which can be particularly problematic in list learning paradigms of the distributed practice effect (although applicable to multiday paradigms, too). Furthermore, equating the number of learning trials across conditions and including a discrete retention interval(s) are also critical design decisions.

A great number of studies evaluating the distributed practice effect in classrooms have appeared in the last decade. This is a promising shift in the published literature and we look forward to more of this work. Well-conducted classroom studies require collaborations between psychologists (who have expertise in research design) and field-specific experts and affiliates, such as school boards, principals, and teachers (who have expertise in curriculum and implementation). These collaborations between distributed practice experts and experts outside psychology are needed so that students in a wide range of fields, including outside traditional academia, can benefit from use of distributed practice. Tables 22.1, 22.2, 22.3, and 22.4 provide a good representation of fields that are ripe for future collaborations. Future hallmark studies will be those that employ a large number of classrooms, teachers, and disciplines and that, ideally, use a randomized controlled trial approach to compare the distributed practice strategy to whatever is the current status quo for classroom learning. We encourage improved dialogue among all collaborators.

Whether in the laboratory or in the classroom, more studies are needed that investigate the distributed practice effect outside of the verbal learning domain. While difficult to design and conduct, and requiring dedication to strong and respectful collaborations, these types of studies are needed to bridge the gap between laboratory and classroom.

Overall, we believe that educators and students alike need to take a hard look at why we teach and why we are motivated to learn. Using detrimental learning strategies like cramming might be a viable option for an immediate assessment, but research shows that in the long run it is often ineffective. Students will need to invest more time in relearning the material if it is needed again in the future. In comparison to other educational interventions, distributed practice has been ranked quite high (#27 out of 195 in a review by Hattie, 2015), and it can and should be used to improve classroom outcomes (e.g., American Association for the Advancement of Science, 1962; Carpenter et al., 2012; Dempster, 1987, 1988; Kiepert, 2009; Pashler et al., 2007). Based on the available empirical evidence and the potential ease with which distributed practice can be implemented, we endorse the use of distributed practice as a means for enhancing the quality of student learning.

References

American Association for the Advancement of Science (1962). Strengthening the behavioral sciences. *Science*, *136*(3512), 233–241. https://doi.org/10.1126/science.136.3512.233

Arthur, W.Jr., Day, E. A., Villado, A. J., Boatman, P. R., Kowollik, V., Bennett Jr., W., & Bhupatkar, A. (2007). *Decay, transfer, and the reacquisition of a complex skill: An investigation of practice schedules, observational rehearsal, and individual differences*. Woburn, MA: Aptima.

Baddeley, A. D. & Longman, D. J. A. (1978). The influence of length and frequency of training session on the rate of learning to type. *Ergonomics*, *21*(8), 627–635. https://doi.org/10.1080/00140137808931764

Baldree, C. L. (2003). The effectiveness of two mathematical instructional programs on the mathematics growth of eighth grade students. (Unpublished doctoral dissertation). University of Georgia, Athens, GA.

Balota, D. A., Duchek, J. M., & Logan, J. M. (2007). Is expanded retrieval practice a superior form of spaced retrieval? A critical review of the extant literature. In J. S. Nairne (ed.), *The foundations of remembering* (pp. 83–105). New York: Psychology Press.

Balota, D. A., Duchek, J. M., Sergent-Marshall, S. D., & Roediger III, H. L. (2006). Does expanded retrieval produce benefits over equal-interval spacing? Explorations of spacing effects in healthy aging and early stage Alzheimer's disease. *Psychology and Aging*, *21*(1), 19–31. https://doi.org/10.1037/0882–7974.21.1.19

Bare, C. E. & Mitchell, R. R. (1972). Experimental evaluation of sensitivity training. *The Journal of Applied Behavioral Science*, *8*(3), 263–276. https://doi.org/10.1177/002188637200800301

Benjamin, A. S. & Tullis, J. (2010). What makes distributed practice effective? *Cognitive Psychology*, *61*(3), 228–247. https://doi.org/10.1016/j.cogpsych.2010.05.004

Bird, S. (2010). Effects of distributed practice on the acquisition of second language English syntax. *Applied Psycholinguistics*, *31*(4), 635–650. https://doi.org/10.1017/S0142716410000172

Bjerrum, A. S., Eika, B., Charles, P., & Hilberg, O. (2016). Distributed practice. The more the merrier? A randomised bronchoscopy simulation study. *Medical Education Online*, *21*(1), 30517. https://doi.org/10.3402/meo.v21.30517

Bjork, E. L. & Bjork, R. A. (2011). Making things hard on yourself, but in a good way: Creating desirable difficulties to enhance learning. In M. A. Gernsbacher, R. W. Pew, L. M. Hough, & J. R. Pomerantz (eds.), *Psychology and the real world: Essays illustrating fundamental contributions to society* (pp. 56–64). New York: Worth Publishers.

Bloom, K. C. & Shuell, T. J. (1981). Effects of massed and distributed practice on the learning and retention of second-language vocabulary. *Journal of Educational Research*, *74* (4), 245–248. https://doi.org/10.1080/00220671.1981.10885317

Budé, L., Imbos, T., van de Wiel, M. W., & Berger, M. P. (2011). The effect of distributed practice on students' conceptual understanding of statistics. *Higher Education*, *62* (1), 69–79. https://doi.org/10.1007/s10734-010–9366-y

Calder, K. M. & Gabriel, D. A. (2007). Adaptations during familiarization to resistive exercise. *Journal of Electromyography and Kinesiology*, *17*(3), 328–335. https://doi.org/10.1016/j.jelekin.2006.02.006

Carpenter, S. K., Cepeda, N. J., Rohrer, D., Kang, S. K., & Pashler, H. (2012). Using spacing to enhance diverse forms of learning: Review of recent research and implications for instruction. *Educational Psychology Review*, *24*(3), 369–378. https://doi.org/10.1007/s10648-012–9205-z

Carpenter, S. K. & DeLosh, E. L. (2005). Application of the testing and spacing effects to name-learning. *Applied Cognitive Psychology*, *19*(5), 619–636. https://doi.org/10.1002/acp.1101

Carpenter, S. K., Pashler, H., & Cepeda, N. J. (2009). Using tests to enhance 8th grade students' retention of U.S. history facts. *Applied Cognitive Psychology*, *23*(6), 760–771. https://doi.org/10.1002/acp.1507

Cepeda, N. J., Pashler, H., Vul, E., Wixted, J. T., & Rohrer, D. (2006). Distributed practice in verbal recall tasks: A review and quantitative synthesis. *Psychological Bulletin*, *132* (3), 354–380. https://doi.org/10.1037/0033–2909.132.3.354

Cepeda, N. J., Vul, E., Rohrer, D., Wixted, J. T., & Pashler, H. (2008). Spacing effects in learning: A temporal ridgeline of optimal retention. *Psychological Science*, *19*(11), 1095–1102. https://doi.org/10.1111/j.1467–9280.2008.02209.x

Cermak, L. S., Verfaellie, M., Lanzoni, S., Mather, M., & Chase, K. A. (1996). Effect of spaced repetitions on amnesia patients' recall and recognition performance. *Neuropsychology*, *10*(2), 219. https://doi.org/10.1037/0894–4105.10.2.219

Christina, W. B. (1974). The effects of massed and distributed practice on the performance of a gross motor skill. (Master's thesis). The College at Brockport, New York.

Cull, W. L. (2000). Untangling the benefits of multiple study opportunities and repeated testing for cued recall. *Applied Cognitive Psychology*, *14*(3), 215–235. https://doi.org/10.1002/(SICI)1099–0720(200005/06)14:3<215::AID-ACP640>3.0.CO;2–1

Dail, T. K. & Christina, R. W. (2004). Distribution of practice and metacognition in learning and long-term retention of a discrete motor task. *Research Quarterly for Exercise and Sport*, *75*(2), 148–155. https://doi.org/10.1080/02701367.2004.10609146

Delaney, P. F., Verkoeijen, P. P., & Spirgel, A. (2010). Spacing and testing effects: A deeply critical, lengthy, and at times discursive review of the literature. *Psychology of Learning and Motivation*, *53*, 63–147. https://doi.org/10.1016/S0079-7421(10)53003–2

Dempster, F. N. (1987). Time and the production of classroom learning: Discerning implications from basic research. *Educational Psychologist*, *22*(1), 1–21. https://doi.org/10.1207/s15326985ep2201_1

(1988). The spacing effect: A case study in the failure to apply the results of psychological research. *American Psychologist*, *43*(8), 627–634. https://doi.org/10.1037/0003-066X.43.8.627

Descours, K. (2013). Teachers' perceptions of critical thinking. (Unpublished master's thesis). York University, Toronto, ON.

Diekelmann, S., Wilhelm, I., & Born, J. (2009). The whats and whens of sleep-dependent memory consolidation. *Sleep Medicine Reviews*, *13*, 309–321. https://doi.org/10.1016/j.smrv.2008.08.002

Donovan, J. J. & Radosevich, D. J. (1999). A meta-analytic review of the distribution of practice effect. *Journal of Applied Psychology*, *84*(5), 795–805. https://doi.org/10.1037/0021–9010.84.5.795

Drake, J. B. (1981). The theory of distributed practice as related to acquisition of psychomotor skills by adolescents in a selected curricular field. *The High School Journal*, *65*(1), 26–32.

(1987). Effects of distributed practice theory on arc welding skill development of agriculture students. *Journal of the American Association of Teacher Educators in Agriculture*, *28*(3), 16–21. https://doi.org/10.5032/jaatea.1987.03016

Dritsas, A. (1950). A study to determine the effectiveness of a relative massing time pattern as compared with an additive time pattern on skill development in typewriting. (Unpublished doctoral dissertation). Boston University, Boston, MA.

Ebbinghaus, H. (1885/1964). *Memory: A contribution to experimental psychology* (trans. H. A. Ruger, C. E. Bussenius, & E. R. Hilgar). New York: Dover Publications.

El-Shamy, S. E. (1976). The effects of time-spacing on outcomes in assertion training for women: The effectiveness of a workshop model (Unpublished doctoral dissertation). Indiana University, Bloomington, IN.

Estes, W. K. (1955). Statistical theory of distributional phenomena in learning. *Psychological Review*, *62*(5), 369–377. https://doi.org/10.1037/h0046888

Farr, R. G., Dey, M. K., & Bloch, E. (1956). The airplane control test: A compensatory pursuit task. *Perceptual and Motor Skills*, *6*(3), 77–80. https://doi.org/10.2466/pms.1956.6.3.77

Fishman, E. J., Keller, L., & Atkinson, R. C. (1968). Massed versus distributed practice in computerized spelling drills. *Journal of Educational Psychology*, *59*(4), 290–296. https://doi.org/10.1037/h0020055

Fitzgerald, M. A. (1952). The effect of two time patterns on developing a secondary motor skill. (Unpublished doctoral dissertation). Boston University, Boston, MA.

Fleishman, E. A. & Parker Jr, J. F. (1962). Factors in the retention and relearning of perceptual-motor skill. *Journal of Experimental Psychology*, *64*(3), 215–226. https://doi.org/10.1037/h0041220

Foot, V. (2016). *Judging Credibility: Can spaced lessons help students think more critically online?* (Unpublished master's thesis). York University, Toronto, ON.

Gagné, R. M. (1977). *The conditions of learning*, 3rd edn. New York: Holt, Rinehart, and Winston.

(1984). Learning outcomes and their effects. *American Psychologist*, *39*(4), 377–385. https://doi.org/10.1037/0003-066X.39.4.377

Gallagher, A. G., Jordan-Black, J. A., & O'Sullivan, G. C. (2012). Prospective, randomized assessment of the acquisition, maintenance, and loss of laparoscopic skills. *Annals of Surgery*, *256*(2), 387–393. https://doi.org/10.1097/SLA.0b013e318251f3d2

Glenberg, A. M. (1976). Monotonic and nonmonotonic lag effects in paired-associate and recognition memory paradigms. *Journal of Verbal Learning and Verbal Behavior*, *15*(1), 1–16. https://doi.org/10.1016/S0022-5371(76)90002–5

(1979). Component-levels theory of the effects of spacing of repetitions on recall and recognition. *Memory and Cognition*, *7*(2), 95–112. https://doi.org/10.3758/BF03197590

Gluckman, M., Vlach, H. A., & Sandhofer, C. M. (2014). Spacing simultaneously promotes multiple forms of learning in children's science curriculum. *Applied Cognitive Psychology*, *28*(2), 266–273. https://doi.org/10.1002/acp.2997

Goossens, N. A. M. C., Camp, G., Verkoeijen, P. P. J. L. et al. (2016). Distributed practice and retrieval practice in primary school vocabulary learning: A multi-classroom study. *Applied Cognitive Psychology*, *30*(5), 700–712. https://doi.org/10.1002/acp.3245

Goverover, Y., Hillary, F. G., Chiaravalloti, N., Arango-Lasprilla, J. C., & DeLuca, J. (2009). A functional application of the spacing effect to improve learning and memory in persons with multiple sclerosis. *Journal of Clinical and Experimental Neuropsychology*, *31*(5), 513–522. https://doi.org/10.1080/13803390802287042

Green, J. L., Weston, T., Wiseheart, M., & Rosenbaum, R. S. (2014). Long-term spacing effect benefits in developmental amnesia: Case experiments in rehabilitation. *Neuropsychology*, *28*(5), 685. https://doi.org/10.1037/neu0000070

Griffin, C. S. (2009). A comparison of the effectiveness and efficiency of traditional phonics-distributed practice, traditional phonics-massed practice, and incremental rehearsal on kindergarten students' letter-sound correspondence performance. (Unpublished doctoral dissertation). The Ohio State University, Columbus, OH.

Grote, M. G. (1995). Distributed versus massed practice in high school physics. *School Science and Mathematics*, *95*(2), 97–101. https://doi.org/10.1111/j.1949–8594.1995.tb15736.x

Harden, R. M. & Stamper, N. (1999). What is a spiral curriculum? *Medical Teacher*, *21*(2), 141–143. https://doi.org/10.1080/01421599979752

Hattie, J. (2015). The applicability of visible learning to higher education. *Scholarship of Teaching and Learning in Psychology*, *1*(1), 79. https://doi.org/10.1037/stl0000021

Hawley, K. S. (2002). Spaced-retrieval effects on name-face recognition in older adults with probable Alzheimer's disease. (Unpublished master's thesis). Louisiana State University, Baton Rouge, LA.

Hertenstein, E. J. (2000). The interaction between learning goal orientation and differentially distributed-practice training designs in labor education. (Unpublished doctoral dissertation). University of Illinois at Urbana-Champaign, Urbana, IL.

Hintzman, D. L. (1974). Theoretical implications of the spacing effect. In R. L. Solso (ed.), *Theories in cognitive psychology: The Loyola Symposium* (pp. 77–99). Potomac, MD: Erlbaum.

Hintzman, D. L., Block, R. A., & Summers, J. J. (1973). Modality tags and memory for repetitions: Locus of the spacing effect. *Journal of Verbal Learning and Verbal Behavior*, *12*(2), 229–238. https://doi.org/10.1016/S0022-5371(73)80013–1

Hood, T. & Ivie, S. D. (2003). Is Saxon Math the answer? *Journal of Philosophy and History of Education*, *53*, 64–82.

Hovland, C. I. (1939). Experimental studies in rote-learning theory. V. Comparison of distribution of practice in serial and paired-associate learning. *Journal of Experimental Psychology*, *25*(6), 622–633. https://doi.org/10.1037/h0062807

Hunt, B. J. (1969). The effects of massed and distributed practice on problem solving (Unpublished doctoral dissertation). University of Nebraska, Lincoln, NE.

Johnson, D. M. & Smith, B. (1987). An evaluation of Saxon's algebra text. *The Journal of Educational Research*, *81*(2), 97–102. https://doi.org/10.1080/00220671.1987.10885804

Jost, A. (1897). Die Assoziationsfestigkeit in ihrer Abhängigkeit von der Verteilung der Wiederholungen [The strength of associations in their dependence on the distribution of repetitions]. *Zeitschrift für Psychologie und Physiologie der Sinnesorgane*, *14*, 436–472.

Joy, J. M., Oliver, J. M., McCleary, S. A., Lowery, R. P., & Wilson, J. M. (2013). Power output and electromyography activity of the back squat exercise with cluster sets. *Journal of Sports Sciences*, *1*, 37–45.

Kang, S. H., Lindsey, R. V., Mozer, M. C., & Pashler, H. (2014). Retrieval practice over the long term: Should spacing be expanding or equal-interval? *Psychonomic Bulletin and Review*, *21*(6), 1544–1550. https://doi.org/10.3758/s13423-014–0636-z

Kapler, I. V., Weston, T., & Wiseheart, M. (2015). Long-term retention benefits from the spacing effect in a simulated undergraduate classroom using simple and complex curriculum material. *Learning and Instruction*, *36*, 38–45. https://doi.org/10.1016/j.learninstruc.2014.11.001

Kauffeld, S. & Lehmann-Willenbrock, N. (2010). Sales training: effects of spaced practice on training transfer. *Journal of European Industrial Training*, *34*(1), 23–37. https://doi.org/10.1108/03090591011010299

Kerfoot, B. P., Shaffer, K., McMahon, G. T., Baker, H., Kirdar, J., Kanter, S., Corbett Jr., E. C., Berkow, R., Krupat, E., & Armstrong, E. G. (2011). Online "spaced education progress-testing" of students to confront two upcoming challenges to medical schools. *Academic Medicine*, *86*(3), 300–306. https://doi.org/10.1097/ACM.0b013e3182087bef

Kiepert, M. H. (2009). An examination of repetition and the spacing effect in the classroom: A self-report survey of teachers. (Unpublished doctoral dissertation). Temple University, Philadelphia, PA.

Kim, C. (2003). Cumulative review: Effects of random alternation of review items on mathematics problem solving. (Unpublished doctoral dissertation). West Virginia University, Morgantown, WV.

Kleinman, M. (1976). The effects of practice distribution on the acquisition of three discrete motor skills. *Research Quarterly. American Alliance for Health, Physical Education and Recreation*, *47*(4), 672–677.

Klingele, W. E. & Reed, B. W. (1984). An Examination of an incremental approach to mathematics. *Phi Delta Kappan*, *65*(10), 712–13.

Knapp, C. G. & Dixon, W. R. (1950). Learning to juggle: I. A study to determine the effect of two different distributions of practice on learning efficiency. *Research Quarterly. American Association for Health, Physical Education and Recreation*, *21*(3), 331–340.

Korben, D. L. (1976). The effects of distributed practice versus massed practice, and behavioral modeling versus script modeling, on assertive training with females. (Unpublished doctoral dissertation). Indiana University, Bloomington, IN.

Kornell, N. (2009). Optimizing learning using flashcards: spacing is more effective than cramming. *Applied Cognitive Psychology*, *23*(9), 1297–1317. https://doi.org/10.1002/acp.1537

Kornell, N. & Bjork, R. A. (2008). Optimising self-regulated study: The benefits – and costs – of dropping flashcards. *Memory*, *16*(2), 125–136. https://doi.org/10.1080/09658210701763899

Kornell, N. & Bjork, R. A. (2008). Learning concepts and categories is spacing the "enemy of induction"? *Psychological science*, *19*(6), 585–592. https://doi.org/10.1111/j.1467–9280.2008.02127.x

Kreutzer, A. (2014). Acute kinematic, kinetic, and hormonal responses to cluster sets in parallel back squat exercise in trained and untrained young men utilizing hypertrophic intensities. (Unpublished master's thesis). Texas Christian University, Fort Worth, TX.

Küpper-Tetzel, C. E. (2014). Strong effects on weak theoretical grounds: Understanding the distributed practice effect. Zeitschrift für Psychologie *[*Journal of Psychology*]*, *222*, 71–81. https://doi.org/10.1027/2151–2604/a000168

Küpper-Tetzel, C. E. & Erdfelder, E. (2012). Encoding, maintenance, and retrieval processes in the lag effect: A multinomial processing tree analysis. *Memory*, *20*(1), 37–47. https://doi.org/10.1080/09658211.2011.631550

Küpper-Tetzel, C. E., Erdfelder, E., & Dickhauser, O. (2014). The lag effect in secondary school classrooms: Enhancing students' memory for vocabulary. *Instructional Science*, *42*(3), 373–388. https://doi.org/10.1007/s11251-013–9285-2

Küpper-Tetzel, C. E., Kapler, I. V., & Wiseheart, M. (2014). Contracting, equal, and expanding learning schedules: The optimal distribution of learning sessions depends on retention interval. *Memory and Cognition. 42*(5), 729–741. https://doi.org/10.3758/s13421-014–0394-1

Laing, R. A. & Peterson, J. C. (1973). Assignments: Yesterday, Today, and Tomorrow – Today. *The Mathematics Teacher*, *66*(6), 508–518.

LaRocco, A. J. (2008). An investigation of the repeated reading intervention for improving reading fluency: A doctoral dissertation. (Unpublished doctoral dissertation). University of Iowa, Iowa City, IA.

Lashley, K. S. (1915). The acquisition of skill in archery. *Papers from the Department of Marine Biology of the Carnegie Institution of Washington*, *7*, 105–128.

Lawrence, D. H. (1949). Acquired distinctiveness of cues: I. Transfer between discriminations on the basis of familiarity with the stimulus. *Journal of Experimental Psychology*, *39*(6), 770–784. https://doi.org/10.1037/h0058097

Lawton, T. W., Cronin, J. B., & Lindsell, R. P. (2006). Effect of interrepetition rest intervals on weight training repetition power output. *The Journal of Strength and Conditioning Research*, *20*(1), 172–176.

Lee, T. D. & Genovese, E. D. (1988). Distribution of practice in motor skill acquisition: Learning and performance effects reconsidered. *Research Quarterly for Exercise and Sport*, *59*(4), 277–287. https://doi.org/10.1080/02701367.1988.10609373

Liang, R. A. (1970). Relative effects of massed and distributed scheduling of topics on homework assignments of eighth grade mathematics students. (Unpublished doctoral dissertation). Ohio State University, Columbus, OH.

Lindsey, R., Mozer, M. C., Cepeda, N. J., & Pashler, H. (2009). Optimizing memory retention with cognitive models. In A. Howes, D. Peebles, & R. Cooper (eds.), *Proceedings of* *the ninth international conference on cognitive modeling (ICCM)*. Manchester: University of Manchester.

Lu, P. K. (1978). Three integrative models of kinetic structure in teaching astronomy. *Journal of Research in Science Teaching*, *15*(4), 249–255. https://doi.org/10.1002/tea.3660150403

Lynch, G. I. S. (1971). Effects of three practice conditions on the acquisition of golf skill. (Unpublished doctoral dissertation). Texas Tech University, Lubbock, TX.

Mackay, S., Morgan, P., Datta, V., Chang, A., & Darzi, A. (2002). Practice distribution in procedural skills training. *Surgical Endoscopy*, *16*(6), 957–961. https://doi.org/10.1007/s00464-001–9132-4

Mayfield, K. H. & Chase, P. N. (2002). The effects of cumulative practice on mathematics problem solving. *Journal of Applied Behavior Analysis*, *35*(2), 105–123. https://doi.org/10.1901/jaba.2002.35–105

McCabe, J. (2011). Metacognitive awareness of learning strategies in undergraduates. *Memory and Cognition*, *39*(3), 462–476. https://doi.org/10.3758/s13421-010–0035-2

McGuigan, F. J. & MacCaslin, E. F. (1955). Whole and part methods in learning a perceptual motor skill. *The American Journal of Psychology*, *68*(4), 658–661. https://doi.org/10.2307/1418796

Miller, A. G. (1948). The effect of various interpolated time patterns on motor learning. (Unpublished doctoral dissertation). Boston University, Boston, MA.

Melton, A. W. (1970). The situation with respect to the spacing of repetitions and memory. *Journal of Verbal Learning and Verbal Behavior*, *9*(5), 596–606. https://doi.org/10.1016/S0022-5371(70)80107–4

Mitchell, E. L., Lee, D. Y., Sevdalis, N., Partsafas, A. W., Landry, G. J., Liem, T. K., & Moneta, G. L. (2011). Evaluation of distributed practice schedules on retention of a newly acquired surgical skill: a randomized trial. *The American Journal of Surgery*, *201*(1), 31–39. https://doi.org/10.1016/j.amjsurg.2010.07.040

Moss, V. D. (1995). The efficacy of massed versus distributed practice as a function of desired learning outcomes and grade level of the student. (Unpublished doctoral dissertation). Utah State University, Logan, UT.

Moulton, C. E., Dubrowski, A., Macrae, H., Graham, B., Grober, E., & Reznick, R. (2006). Teaching surgical skills: What kind of practice makes perfect? *Annals of Surgery*, *244*(3), 400–409. https://doi.org/10.1097/01.sla.0000234808.85789.6a

Mozer, M. C., Pashler, H., Cepeda, N. J., Lindsey, R., & Vul, E. (2009). Predicting the optimal spacing of study: A multiscale context model of memory. In Y. Bengio, D. Schuurmans, J. Lafferty, C. K. I. Williams, & A. Culotta (Eds.), *Advances in Neural Information Systems 22*. San Diego, CA: Neural Information Processing Systems Foundation.

Murray, J. T. (1983). Spacing phenomena in human memory: A study phase retrieval interpretation. (Unpublished doctoral dissertation). University of California, Los Angeles, Los Angeles, CA.

Murphree, T. R. (1971). Effects of massed and distributed practice upon motor learning and retention of a novel gross motor task. (Unpublished doctoral dissertation). North Texas State University, Denton, TX.

Murphy, H. H. (1916). Distribution of practice periods in learning. *Journal of Educational Psychology*, *7*(3), 150–162. https://doi.org/10.1037/h0074113

Oliver, J. M. (2012). *Intra-set rest intervals in hypertrophic training: Effects on hypertrophy, strength, power, and myosin heavy chain composition* (Unpublished doctoral dissertation). Texas A&M University, College Station, TX.

Pamplona, C., Ysunza, A., Patiño, C., Ramírez, E., Drucker, M., & Mazón, J. J. (2005). Speech summer camp for treating articulation disorders in cleft palate patients. *International Journal of Pediatric Otorhinolaryngology*, *69*(3), 351–359. https://doi.org/10.1016/j.ijporl.2004.10.012

Pashler, H., Bain, P. M., Bottge, B. A., Graesser, A., Koedinger, K., McDaniel, M., & Metcalfe, J. (2007). *Organizing instruction and study to improve student learning* (NCER 2007–2004). Washington, DC: National Center for Education Research, Institute of Education Sciences, and US Department of Education. http://ncer.ed.gov.

Peterson, J. C. (1971). Four organizational patterns for assigning mathematics homework. *School Science and Mathematics*, *71*(7), 592–596. https://doi.org/10.1111/j.1949–8594.1971.tb13760.x

Peterson, L. R., Wampler, R., Kirkpatrick, M., & Saltzman, D. (1963). Effect of spacing presentations on retention of a paired associate over short intervals. *Journal of Experimental Psychology*, *66*(2), 206–209. https://doi.org/10.1037/h0046694

Raaijmakers, J. G. (2003). Spacing and repetition effects in human memory: Application of the SAM model. *Cognitive Science*, *27*(3), 431–452. https://doi.org/10.1207/s15516709cog2703_5

Rasch, B. & Born, J. (2013). About sleep's role in memory. *Physiological Reviews*, *93*(2), 681–766. https://doi.org/10.1152/physrev.00032.2012

Rawson, K. A. & Kintsch, W. (2005). Rereading effects depend on time of test. *Journal of Educational Psychology*, *97*(1), 70–80. https://doi.org/10.1037/0022–0663.97.1.70

Rea, C. P. & Modigliani, V. (1987). The spacing effect in 4-to 9-year-old children. *Memory and Cognition*, *15*(5), 436–443. https://doi.org/10.3758/BF03197733

Revak, M. (1997). Distributed practice: More bang for your homework buck. *Florida Journal of Educational Research*, *37*(1), 36–48.

Reynolds, J. H. & Glaser, R. (1964). Effects of repetition and spaced review upon retention of a complex learning task. *Journal of Educational Psychology*, *55*(5), 297–308. https://doi.org/10.1037/h0040734

Riches, N. G., Tomasello, M., & Conti-Ramsden, G. (2005). Verb learning in children with SLI: Frequency and spacing effects. *Journal of Speech, Language, and Hearing Research*, *48*(6), 1397–1411. https://doi.org/10.1044/1092–4388(2005/097)

Robinson, E. S. (1921). The relative efficiencies of distributed and concentrated study in memorizing. *Journal of Experimental Psychology*, *4*(5), 327–343. https://doi.org/10.1037/h0073490

Rogers, D. (2004). Evaluating spacing of practice effects on the learning of shortcut keys (Unpublished master's thesis). San Jose State University, San Jose, CA.

Rohrer, D. & Taylor, K. (2006). The effects of overlearning and distributed practise on the retention of mathematics knowledge. *Applied Cognitive Psychology*, 20, 1209–1224. https://doi.org/10.1002/acp.1266

(2007). The shuffling of mathematics problems improves learning. *Instructional Science*, *35*(6), 481–498. https://doi.org/10.1007/s11251-007–9015-8

Rovee-Collier, C., Evancio, S., & Earley, L. A. (1995). The time window hypothesis: Spacing effects. *Infant Behavior and Development*, *18*(1), 69–78. https://doi.org/10.1016/0163–6383(95)90008-X

Rowe, M. K. & Craske, M. G. (1998). Effects of an expanding-spaced vs massed exposure schedule on fear reduction and return of fear. *Behaviour Research and Therapy*, *36* (7–8), 701–717. https://doi.org/10.1016/S0005-7967(97)10016-X

Rubin-Rabson, G. (1940). Studies in the psychology of memorizing piano music: II. A comparison of massed and distributed practice. *Journal of Educational Psychology*, *31*(4), 270–284. https://doi.org/10.1037/h0061174

Ruch, T. C. (1928). Factors influencing the relative economy of massed and distributed practice in learning. *Psychological Review*, *35*(1), 19–45. https://doi.org/10.1037/h0074423

Saxon, J. (1982). Incremental development: A breakthrough in mathematics. *The Phi Delta Kappan*, *63*(7), 482–484.

Seabrook, R., Brown, G. D. A., & Solity, J. E. (2005). Distributed and massed practice: From laboratory to classroom. *Applied Cognitive Psychology*, *19*(1), 107–122. https://doi.org/10.1002/acp.1066

Scheel, M. H. (2007). Massing practice increases rate and errors on a virtual water jar task. (Unpublished doctoral dissertation). University of Nevada, Reno, Reno, NV.

Schendel, J. D. & Hagman, J. D. (1980). *On sustaining procedural skills over prolonged retention intervals* (Research Report No. 1298). Alexandria, VA: Army Research Institution for the Behavioral and Social Sciences. (Accession No. AD-A120 758)

Scott, M. G. (1954). Learning rate of beginning swimmers. *Research Quarterly. American Association for Health, Physical Education and Recreation*, *25*(1), 91–99.

Shea, C. H., Lai, Q., Black, C., & Park, J. H. (2000). Spacing practice sessions across days benefits the learning of motor skills. *Human Movement Science*, *19*(5), 737–760. https://doi.org/10.1016/S0167-9457(00)00021-X

Simmons, A. (2012). Distributed practice and procedural memory consolidation in musicians' skill learning. *Journal of Research in Music Education*, *59*(4), 357–368. https://doi.org/10.1177/0022429411424798

Simone, P. M., Bell, M. C., & Cepeda, N. J. (2013). Diminished but not forgotten: Effects of aging on magnitude of spacing effect benefits. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *68*(5), 674–680. https://doi.org/10.1093/geronb/gbs096

Singer, R. N. (1965). Massed and distributed practice effects on the acquisition and retention of a novel basketball skill. *Research Quarterly. American Association for Health, Physical Education and Recreation*, *36*(1), 68–77.

Smith, S. M. & Rothkopf, E. Z. (1984). Contextual enrichment and distribution of practice in the classroom. *Cognition and Instruction*, *1*(3), 341–358. https://doi.org/10.1207/s1532690xci0103_4

Sobel, H. S., Cepeda, N. J., & Kapler, I. V. (2011). Spacing effects in real-world classroom vocabulary learning. *Applied Cognitive Psychology*, *25*(5), 763–767. https://doi.org/10.1002/acp.1747

Son, L. K. & Simon, D. A. (2012). Distributed learning: Data, metacognition, and educational implications. *Educational Psychology Review*, *24*(3), 379–399. https://doi.org/10.1007/s10648-012–9206-y

Spruit, E. N., Band, G. P., & Hamming, J. F. (2015). Increasing efficiency of surgical training: effects of spacing practice on skill acquisition and retention in laparoscopy training. *Surgical Endoscopy*, *29*(8), 2235–2243. https://doi.org/10.1007/s00464-014–3931-x

Thios, S. J., & D'Agostino, P. R. (1976). Effects of repetition as a function of study-phase retrieval. *Journal of Verbal Learning and Verbal Behavior*, *15*(5), 529–536. https://doi.org/10.1016/0022–5371(76)90047–5

Tobias, J. V. (1976). *Massed versus distributed practice in learned improvement of speech intelligibility* (Report No. FAA-AM-76–3). Oklahoma City, OK: FAA Civil Aeromedical Institute, Office of Aviation Medicine, Federal Aviation Administration.

Toppino, T. C., Kasserman, J. E., & Mracek, W. A. (1991). The effect of spacing repetitions on the recognition memory of young children and adults. *Journal of Experimental Child Psychology*, *51*(1), 123–138. https://doi.org/10.1016/0022–0965(91)90079–8

Tran, O. T. K. (2007). Promoting social and emotional learning in schools: An investigation of massed versus distributed practice schedules and social validity of the Strong Kids curriculum in late elementary aged students. (Unpublished doctoral dissertation). University of Oregon, Eugene, OR.

Ukrainetz, T. A., Ross, C. L., & Harm, H. M. (2009). An investigation of treatment scheduling for phonemic awareness with kindergartners who are at risk for reading difficulties. *Language, Speech, and Hearing Services in Schools*, *40*(1), 86–100. https://doi.org/10.1044/0161–1461(2008/07–0077)

Urwiller, S. L. (1971). A comparative study of achievement, retention, and attitude toward mathematics between students using spiral homework assignments and students using traditional homework assignments in second year algebra. (Unpublished doctoral dissertation). University of Nebraska-Lincoln, Lincoln, NE.

Vash, C. L. (1989). Comment on Dempster. *American Psychologist*, *44*(12), 1547. https://doi.org/10.1037/0003-066X.44.12.1547.a

Verdaasdonk, E. G. G., Stassen, L. P. S., Van Wijk, R. P. J., & Dankelman, J. (2007). The influence of different training schedules on the learning of psychomotor skills for endoscopic surgery. *Surgical Endoscopy*, *21*(2), 214–219. https://doi.org/10.1007/s00464-005–0852-8

Verkoeijen, P. P. J. L., Rikers, R. M. J. P., & Ozsoy, B. (2008). Distributed rereading can hurt the spacing effect in text memory. *Applied Cognitive Psychology*, *22*(5), 685–695. https://doi.org/10.1002/acp.1388

Vlach, H. A. (2014). The spacing effect in children's generalization of knowledge: allowing children time to forget promotes their ability to learn. *Child Development Perspectives*, *8*(3), 163–168. https://doi.org/10.1111/cdep.12079

Vlach, H. A. & Sandhofer, C. M. (2012). Distributing learning over time: The spacing effect in children's acquisition and generalization of science concepts. *Child Development*, *83*(4), 1137–1144. https://doi.org/10.1111/j.1467–8624.2012.01781.x

Weaver, J. R. (1976). The relative effects of massed versus distributed practice upon the learning and retention of eighth grade mathematics. (Unpublished doctoral dissertation). University of Oklahoma, Norman, OK.

Webb, C. L. (2011). Schedule distribution and motor learning guided treatment with childhood apraxia of speech. (Unpublished master's thesis). East Carolina University, Greenville, NC.

Willardson, J. M. & Burkett, L. N. (2006). The effect of rest interval length on the sustainability of squat and bench press repetitions. *Journal of Strength and Conditioning Research*, *20*(2), 400–403.

Wineland, J. N. & Stephens, L. (1995). Effects of spiral testing and review on retention and mathematical achievement for below-average eighth-and ninth-grade students.

International Journal of Mathematical Education in Science and Technology, *26*(2), 227–232. https://doi.org/10.1080/0020739950260207

Wiseheart, M., D'Souza, A. A., & Chae, J. (2017). Lack of spacing effects during piano learning. *PLoS ONE*, *12*, e0182986. https://doi.org/10.1371/journal.pone.0182986

Wogalter, M. S., Jarrard, S. W., & Cayard, J. A. (1991). Massed versus distributed exposure and imaging of faces: Changing the test view. *Current Psychology*, *10*(4), 281–288. https://doi.org/10.1007/BF02686900

Yazdani, M. A. & Zebrowski, E. (2006). Spaced reinforcement: An effective approach to enhance the achievement in plane geometry. *Journal of Mathematical Sciences and Mathematics Education*, *1*(1), 37–43.

Young, O. G. (1954). Rate of learning in relation to spacing of practice periods in archery and badminton. *Research Quarterly. American Association for Health, Physical Education and Recreation*, *25*(2), 231–243.

Zechmeister, E. B. & Shaughnessy, J. J. (1980). When you know that you know and when you think that you know but you don't. *Bulletin of the Psychonomic Society*, *15*(1), 41–44. https://doi.org/10.3758/BF03329756