Science of Learning Strategy Series: Article 1, Distributed Practice

Thomas J. Van Hoof, MD, EdD; Megan A. Sumeracki, PhD; Christopher R. Madan, PhD

Abstract: Distributed practice is an evidence-based, learning-science strategy that is relevant to the planning and implementation of continuing professional development (CPD). Spacing-out study or practice over time allows the brain multiple opportunities to process new and complex information in an efficient way, thus increasing the likelihood of mastery and memory. Research from cognitive psychology and neuroscience provide the rationale for distributed practice, and examples of its implementation in health professions education have begun to appear in the literature. If used appropriately or extended creatively, some common CPD interventions can fully leverage distributed practice. Through increased understanding, CPD planners can benefit from distributed practice in efforts to improve educational activities, and CPD participants can benefit by making more informed educational choices.

Keywords: science of learning, distributed practice, distributed learning, spacing, continuing education, continuing professional development

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ABOUT THE SCIENCE OF LEARNING STRATEGY SERIES

Consistent with a recent *Journal of Continuing Education in the Health Professions'* editorial by Kitto about informing the continuing professional development (CPD) imagination,[1] the emerging and interdisciplinary field of the science of learning (learning science), which concerns itself with how the brain learns and remembers important information, is a compelling but relatively unfamiliar field that stands to inspire CPD participants and planners to think about educational interventions differently. Moreover, learning science has compiled evidence in support of a set of strategies[2–4] that can help CPD more effectively influence clinician knowledge, skill, attitude, competence, and even performance. The purpose of the series is to bring attention to two, evidence-based, learning-science strategies, and to provide some background that might be helpful to CPD stakeholders considering the strategies. One strategy, "retrieval practice," is the focus of the second article of the series, and retrieval practice concerns how one spends time while learning. The other strategy and the focus of this article is "distributed practice," which concerns when one schedules learning sessions. Distributed practice is also known as "distributed learning" and "spacing" and by its benefits, the "spacing effect."

THE ESSENCE OF DISTRIBUTED PRACTICE

The essence of distributed practice is that any significant effort put toward learning or practice is better spread out over time as opposed to massed, as in "massed practice" or "cramming."[5] For example, if one had 6 hours to devote to meaningful learning, time would be better spent in small increments (1–2 hours) on multiple days rather than in one large increment on a single day. Once new information is in working memory, or is activated in our immediate consciousness, additional effort spent with that information offers diminishing returns. In other words, continuing to rehearse or to go over the information at one single time does not provide much of a benefit. Instead, coming back to information repeatedly with cognitive breaks (spaced) between learning sessions—with sleep being the best break[6]—stabilizes the brain network that represents the information. Continuous repetition without cognitive breaks does not activate as much of the brain and does not provide the varied cues (eg, time, place, circumstance, alertness, and mood) associated with different study sessions. For any given effort, distributed practice is superior to massed practice for improving mastery and memory for new information.[5]

A clear example comparing distributed practice and massed practice comes from graduate medical education involving skill acquisition. In a randomized controlled trial, Moulton et al[7] compared two similar groups of surgical residents learning microvascular anastomosis. The massed practice group received four 2-hour training sessions on a single day, whereas the distributed practice group received one 2-hour training session per week for four consecutive weeks. Other than the scheduling difference, the training was the same for both groups. On a retention test using synthetic tissues one month post-training for both groups, the distributed group outperformed the massed group on most outcome measures. More importantly, however, the distributed group outperformed the

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Dr. Van Hoof: *Associate Professor, University of Connecticut School of Nursing, Storrs, CT and Associate Professor, Department of Public Health Sciences, University of Connecticut School of Medicine, Farmington, CT.* ***Dr. Sumeracki:*** *Associate Professor, Department of Psychology, Rhode Island College.* ***Dr. Madan:*** *Assistant Professor, School of Psychology, University of Nottingham, Nottingham, United Kingdom.*

Correspondence: *Thomas J. Van Hoof, MD, EdD, University of Connecticut, 231 Glenbrook Road, Unit 4026, Storrs, CT 06269-4026; e-mail: tom.vanhoof@uconn.edu.*

massed group on a "transfer test," ie, applying the skill to vessels in a live, anesthetized animal, a circumstance in which neither group practiced. Despite acknowledging the logistical challenges associated with a multiple-session course versus a single-session course, the authors recommend considering the distributed approach for learning surgical skills in the context of both graduate medical education and CPD.

Classic Research Underlying Distributed Practice

Research on distributed practice and the first experimental study of memory date back to the 19th century, when Ebbinghaus[8] intensively studied his own learning of nonsense syllables over the course of many months. He used nonsense syllables so that he could avoid making connections to meaningful content, as he wanted to learn completely new information. Ebbinghaus is famous for plotting the forgetting curve and showing that over time humans lose access to learned information. The forgetting curve tends to be exponential, such that we lose access to the great amount of information in a relatively short amount of time (hours) and forgetting tapers off but continues in the long-run (days, weeks, or months). In his classic work, Ebbinghaus also found that additional repetitions were effective at slowing the rate of forgetting and that repetitions were effective when they were distributed over time. Since this very early work, countless studies have found similar effects across a wide range of disciplines, learners, and contexts, and there is no shortage of reviews on this topic.[9,10] Furthermore, spacing improves learning in a number of different domains, including verbal learning,[11] problem solving,[12] and skill acquisition.[13] Synthesizing this work, Cepeda et al[5] conducted a large meta-analysis reaffirming that distributing learning over time with at least a 1-day space maximizes long-term retention of that information.

Neuroscience Underpinnings of Distributed Practice

When a person processes information for the first time, their brain activity is more extensive, that is, engages more parts of the brain. For example, initial processing involves the hippocampus, part of the temporal lobe that coordinates processing of information (Figure 1) and many regions of the cerebral cortex depending on the senses involved and the information's meaning to the learner. If repetition occurs during the initial session, the brain will process the information less exhaustively and less extensively[15,16] and diminish the involvement of the hippocampus in that processing. However, if spacing of several days or weeks exists between repeated attempts (ie, distributed practice across a relatively brief period), each session is more like the initial one in the sense that the brain is extensively activated[17] and continues to involve the hippocampus. In other words, by distributing practice over a period of days or weeks, it becomes easier to reactivate a memory of previous information and to continue to engage extensive brain regions.

Over longer time periods (eg, months or years), distributed practice can result in information becoming available more as a fact (semantic memory) than as an experience (episodic memory). In this circumstance, the role of the hippocampus becomes less critical in retrieving the information (Figure 2). For example, Sommer[18] demonstrated this point in a longitudinal study. On a computer screen, participants learned arbitrary associations between pictures and locations and were repeatedly presented and tested over the course of approximately 300 days. During presentation and

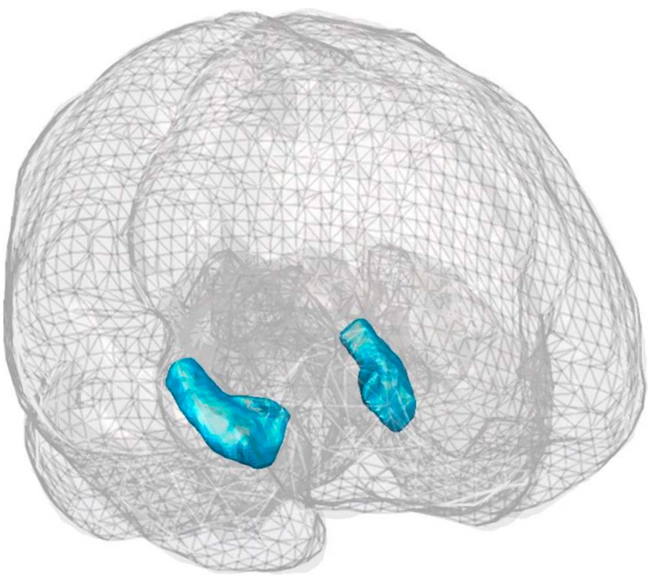

FIGURE 1. Illustration of the hippocampus structure within a transparent three-dimensional brain outline. Reprinted with permission.[14]

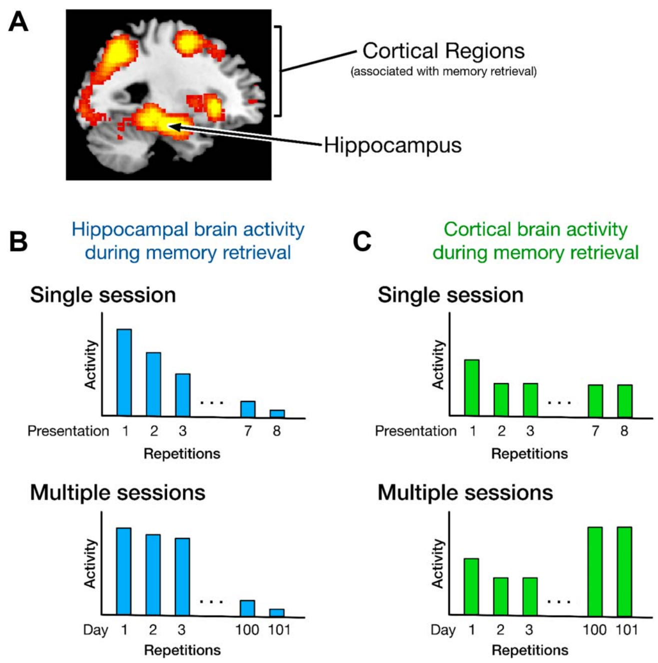

FIGURE 2. Brain regions and activations related to memory retrieval over different time scales. A, Brain regions associated with memory retrieval, in particular, the hippocampus along with regions of the cerebral cortex. Brain activity is shown as regional activations from fMRI data, overlaid on a structural MRI. B and C, illustrate brain activity in the (B) hippocampus and (C) cortical regions associated with memory retrieval over multiple repetitions that are either within a single experimental session or across multiple sessions. Within a single session, the hippocampal activity will be attenuated with each subsequent presentation, whereas activation in cortical regions is slightly reduced on the second presentation and is maintained at this level for later presentations. However, across multiple sessions, the hippocampal activity will reach nearly the same level and will diminish much more gradually. In this case, the activity in cortical regions will be relatively low in early sessions and later become higher after distributed practice. In this way, the cortical activity becomes decoupled from the hippocampal activity, as the information transitions from episodic memory to semantic memory.

testing, the study measured brain activity using functional magnetic resonance imaging (fMRI) at days 1 and 2, at several sessions around day 100, and at several sessions around day 300. In the first sessions (days 1 and 2), retrieval of the learned associations engaged the hippocampus; however, the hippocampal engagement diminished in later sessions (around days 100 and 300). By contrast, activity in regions of the cerebral cortex increased in later sessions, corresponding to the gradual acquisition of knowledge (creation of semantic memory) without the need for their accompanying experiences (episodic memory). In other words, through longer-term distributed practice, information became less reliant on the episodic memory system and more reliant on the semantic one, enhancing expertise in the newly learned domain.

Examples of CPD Studies Involving Distributed Practice

Often in conjunction with retrieval practice, a strategy to be described in the second article of the series, the authors found a variety of CPD studies of distributed practice in the literature from different countries and involving multiple health care professions and specialties. Although not all studies that involved comparisons demonstrated a benefit to distributed practice in outcomes measured,[19] the majority casts a favorable light on the strategy. In fact, a recent systematic review of distributed practice in CPD specifically found that spaced activities (mostly online) can be effective in improving clinician knowledge, skill, attitude (confidence), behavior (including performance), and possibly patient outcomes.[3] Based on published research, the authors chose three examples to illustrate the strategy of distributed practice in the context of CPD.

As the first example, in an effort to decrease inappropriate prostate-specific antigen testing among primary care providers (nurse practitioners, physicians, and physician assistants) working in a region of the US Veterans Affairs system, Kerfoot et al[20] published a randomized controlled trial comparing a control group (no intervention) with a "spaced education" cohort, which received four cycles of nine emails (0–2 emails per week) over a 36-week intervention period. Each email consisted of a clinical scenario with a question about whether a prostate-specific antigen test was appropriate, and participants received immediate feedback (the answer with explanation reflecting clinical practice guidelines) after responding.

As a second example, in a prospective longitudinal study of a course (fundamentals of laparoscopic surgery) to develop minimally invasive surgical skills among 57 practicing surgeons in Brazil, Nakata et al[21] demonstrated that an in-person, simulator-based, long-term course (three sessions spread evenly—every four months—over a 1-year period) is a feasible alternative to the single, intensive (weekend) short-term course that typifies post-training options.

As a third example, Robinson et al[22] report quantitative and qualitative results of a pilot study of a brief "spaced education" program to impact the knowledge and referral patterns of Australian health care providers (ie, primary care physicians, nurses, medical oncologists, and gynecology–oncology fellows) to reflect guideline updates on genetic assessment and testing for women with particular types of cancer. On spaced (every 5 or 8 days) and repeated intervals (until participants answered each question correctly twice), participants received emails with a case, question, choices, and following a response, the results (with peer comparison), a take-home message, detailed explanation, and reference.

Recommendations for CPD Participants and Planners

What can CPD participants do to leverage the benefits of distributed practice?

For CPD participants considering educational options to make significant improvements in knowledge, skill, attitude, and other important outcomes, selecting a longitudinal activity that meets relatively briefly but multiple times with some space (≥1 day) between sessions is a better strategy than a single event. Multiple interactions over time reflect the brain's need for iterative cycles of encoding (considering information in working memory), consolidation (storing information in long-term memory), and retrieval (accessing what is stored for additional consideration) that are critical to mastery and memory (Appendix, Supplemental Digital Content 1, http://links.lww.com/JCEHP/A96). However, participants can transform a single, educational event into a spaced one by taking advantage of event preactivities, such as pretests or needs assessments, and event postactivities, such as post-tests and clinician reminders. Participants can also create their own preactivities and postactivities by reviewing performance measurement and feedback reports that are increasingly available from health plans, talking with colleagues and patients about barriers to care, and/or reflecting on a challenging case that raises questions about opportunities for improvement. Turning any learning opportunity into a process rather than an event can increase its learning value by distributing practice.

What can CPD planners do to leverage the benefits of distributed practice?

CPD planners can enhance the educational value of an activity by offering multiple sessions spread-out over time. Some common CPD structures, such as grand rounds, performance improvement, educational outreach, and practice facilitation lend themselves to the advantages of distributed practice, as they involve (or can involve) repeated, brief interactions over time. If an event (eg, national conference) is still necessary or desirable for other reasons, such as networking and collaboration, planners can engage learners before and after the conference through meaningful virtual interactions. Emails with links to poignant examples can predispose learners to content that the conference will address, and challenging cases can generate cognitive dissonance regarding relevant content. After the conference, planners can reinforce important content through post-tests, electronic health record tools (clinician reminders and documentation prompts), patient-mediated interventions (patient reminders), and follow-up on commitments to change made at the conference. Specialty societies (state chapters) and other organizations can offer complementary activities, such as quality improvement collaboratives, which build on a conference theme.

As one example of a national conference that offered preactivities and postactivities to improve long-term retention of knowledge, the American Academy of Neurology's 2012 conference conducted a study of four topics (ie, epilepsy, multiple sclerosis, headache, and child neurology), each addressed through an in-person short course offered as part of the conference.[23] All recruited participants completed a pretest before the conference and experienced each of the courses during the conference. The control group received no follow-up, but two intervention groups received virtual follow-up, one through repeated quizzing and the other through repeated studying. Finally, 5.5 months after the conference, all participants completed a knowledge post-test, which was identical to the pretest. Although the study's details are beyond the scope of this article, the authors reported that the repeated quizzing group demonstrated significantly better long-term knowledge retention compared with the repeated study and control groups. Through repeated testing (another term for retrieval practice), the study provides an example of a way to accomplish distributed practice in a traditional educational event such as a conference.

CONCLUSION

Distributed practice is the act of spreading-out or spacing study to improve important educational and patient-care outcomes in CPD. Cognitive psychology research in support of distributed practice dates back over a century, and the field of neuroscience has begun to offer biological explanations to support the strategy's effectiveness. Although some logistical challenges exist, examples from CPD specifically and health professions education generally have begun to appear in the literature, and these examples have clear implications for participants and planners alike. Participants of CPD should seek activities that reflect a process similar to learning itself. Through needs assessment, pretests and post-tests, and performance measurement and feedback of patient care data, participants can transform one-time events into more effective mechanisms for learning and change. Educators planning CPD activities should offer longitudinal programs that are necessarily distributed, or planners should extend a single event through one or more educational and quality improvement interventions to accomplish spacing. Distributed practice can inform the collective imagination of participants and planners and, in doing so, improve the effectiveness of CPD activities.

Lessons for Practice

- Distributed practice or spacing is an evidence-based strategy that supports learning and memory through multiple study or practice sessions separated by cognitive breaks.
- Participants of CPD events can transform nonspaced activities into distributed ones through needs assessments, pretests and post-tests, and performance measurement and feedback of patient care data.
- Educators planning continuing professional activities can accomplish distributed practice by offering longitudinal programs that pair events with one or more educational or quality improvement interventions that occur before and/or after the event.

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Science of Learning Strategy Series: Article 2, Retrieval Practice

Thomas J. Van Hoof, MD, EdD; Christopher R. Madan, PhD; Megan A. Sumeracki, PhD

Abstract: Retrieval practice is an evidence-based, science of learning strategy that is relevant to the planning and implementation of continuing professional development (CPD). Retrieval practice requires one to examine long-term memory to work with priority information again in working memory. Retrieval practice improves learning in two ways. It improves memory for the information itself (direct benefit), and retrieval practice provides feedback about what needs additional effort (indirect). Both benefits contribute significantly to durable learning. Research from cognitive psychology and neuroscience provides the rationale for retrieval practice, and examples of its implementation in health professions education are increasingly available in the literature. Through appropriate utilization, CPD participants can benefit from retrieval practice by making more-informed educational choices, and CPD planners can benefit in efforts to improve educational activities.

Keywords science of learning, retrieval practice, practice testing, test-enhanced learning, self-testing, continuing education, continuing professional development

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ABOUT THE SCIENCE OF LEARNING STRATEGY SERIES

Consistent with a recent *Journal of Continuing Education in the Health Professions'* editorial by Kitto about informing the continuing professional development (CPD) imagination,[1] the emerging and interdisciplinary field of the science of learning (learning science), which concerns itself with how the brain learns and remembers important information, is a compelling but relatively unfamiliar field that stands to inspire CPD participants and planners to think about educational interventions differently. Moreover, learning science has compiled evidence in support of a set of strategies[2–5] that can help CPD more effectively influence clinician knowledge, skill, attitude, competence, and even performance. The purpose of the series is to bring attention to evidence-based, learning-science strategies and to provide some background that might be helpful to CPD stakeholders considering the strategies. The first series' article on "distributed practice" focused on when one schedules learning sessions, which should be spread out to allow participants more time and more opportunities to process important information.[6] Here in this second article, the authors focus on how one spends time while learning by providing an overview of "retrieval practice." Retrieval practice is known by many terms, such as "practice testing," "test-enhanced learning," and "self-testing," and by its benefits, the "testing effect."

THE ESSENCE OF RETRIEVAL PRACTICE

The essence of retrieval practice is bringing to mind (eg, as one would during a test) previously studied information. Although one can certainly learn from "high-stakes" tests (eg, licensing examinations) used for summative or judgment purposes, retrieval practice typically refers to "no-stakes" or "low-stakes" tests used for formative or improvement purposes.[7] Examples of no-stakes retrieval practice include activities such as quizzing oneself with flashcards, completing problems or questions at the end of a chapter, and taking old examinations.[7] An example of low-stakes retrieval practice might be a quiz that counts for a small number of points or as extra-credit. What seems to be key to testing's benefits is the extent to which it requires additional processing of important information, elaboration of the memory, and thinking back to the initial learning episode.[8,9] The more a retrieval practice activity reflects priority content, mirrors authentic information use, includes feedback, and is spaced and repeated, the better.[8]

Retrieval practice is believed to provide benefits through direct and indirect mechanisms.[10] The direct benefit refers to "…the act of taking a test itself." [10p.182] Leamnson[11] explains this well: "Intense concentration, under a little pressure, while wrestling with language, cannot but do something to the brain;"[11p.111] and, he recommends recall-style questions (open-ended/essay) over recognition-style (multiple-choice) ones. However, some research suggests that multiple-choice questions can be just as effective if written well.[12,13] Roediger and Karpicke give examples of the indirect or "mediated" effect of testing as studying continuously throughout a course (ie, distributed practice using cumulative examinations), learning from feedback on practice tests, and using results to direct future study efforts.[10] Moreover, if one experiences significant

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Mr. Thomas J. Van Hoof, MD, EdD: Associate Professor, University of Connecticut School of Nursing, Storrs, and Associate Professor, Department of Public Health Sciences, University of Connecticut School of Medicine, Farmington, CT. **Mr. Christopher R. Madan, PhD:** Assistant Professor, School of Psychology, University of Nottingham, Nottingham, United Kingdom. **Ms. Megan A. Sumeracki, PhD:** Assistant Professor, Department of Psychology, Rhode Island College, Rhode Island, United Kingdom.

Correspondence: Thomas J. Van Hoof, MD, EdD, University of Connecticut, 231 Glenbrook Road, Unit 4026, Storrs, CT 06269-4026; e-mail: tom.vanhoof@uconn.edu.

test anxiety, practice tests can help by desensitizing one to testing conditions, especially if one takes a practice test under time and other examination-related constraints.[11]

In addition to tests being used effectively throughout a learning activity, tests given before a learning activity (pretests) offer benefits too,[14] perhaps by "priming students to focus on key information and cognitive activities encountered during study." [15p.11] Study of pretests specifically in CPD is warranted, but given that pretests can serve as a way to complete a needs assessment, an evidence-based strategy in CPD,[16] issuing pretests is a defensible action currently, especially in light of their potential learning value, even if only indirect.[17]

Controlling for the benefits of distributed practice, a clear example of comparing repeated testing to repeated studying comes from graduate medical education. In a randomized controlled trial of long-term retention of information, Larsen et al[18] exposed counterbalanced (overlapping) groups of pediatric and emergency medicine residents to an interactive, one-hour teaching session on status epilepticus and myasthenia gravis followed by either repeated studying (review sheets) or by repeated testing (short-answer questions with feedback) immediately after the session, at 2 weeks, and at 4 weeks. Despite a relatively small sample size, on the final test about 6 months after the interactive session, repeated testing resulted in statistically significant results ($P < .001$) and educationally significant scores (13% higher) compared with repeated studying.

CLASSIC RESEARCH UNDERLYING RETRIEVAL PRACTICE

Like the research on distributed practice, research on the benefits of retrieval date back over 100 years.[19] Since then, considerable research demonstrates the benefits of retrieval practice, both through testing and through other retrieval-based learning activities (eg, concept mapping from memory).[20] Furthermore, retrieval practice can improve learning of content and its application.[9] In a classic and frequently cited set of experiments, Roediger and Karpicke[21] demonstrated the direct benefits of retrieval on learning. In one experiment, college students engaged in learning conditions that required they study a text passage for 5 minutes and then either continue studying or recall what they could from memory (Figure 1). In one condition, students studied a passage four times in a row (SSSS). In a second condition, students studied three times and recalled what they could once (SSSR). Finally, in a third condition, students studied once and recalled three times (SRRR). Learning was measured through a final test either 5 minutes or 1 week after learning. After 5 minutes, those in the SSSS group performed best, while those in the SRRR group performed worst. However, after 1 week, significant learning benefits of retrieval practice were observed. Final test scores of students in the SRRR group were 20% higher than those of students in the SSSS group, with the SSSR group falling in-between. Importantly, students in the SRRR and SSSR groups never saw the passage again after recall, demonstrating long-term, direct effects of retrieval on learning, even in the absence of feedback.

NEUROSCIENCE UNDERPINNINGS OF RETRIEVAL PRACTICE

Given the significant effects of retrieval practice on learning, several studies have examined how retrieval practice occurs within the brain. Of particular interest are studies that have

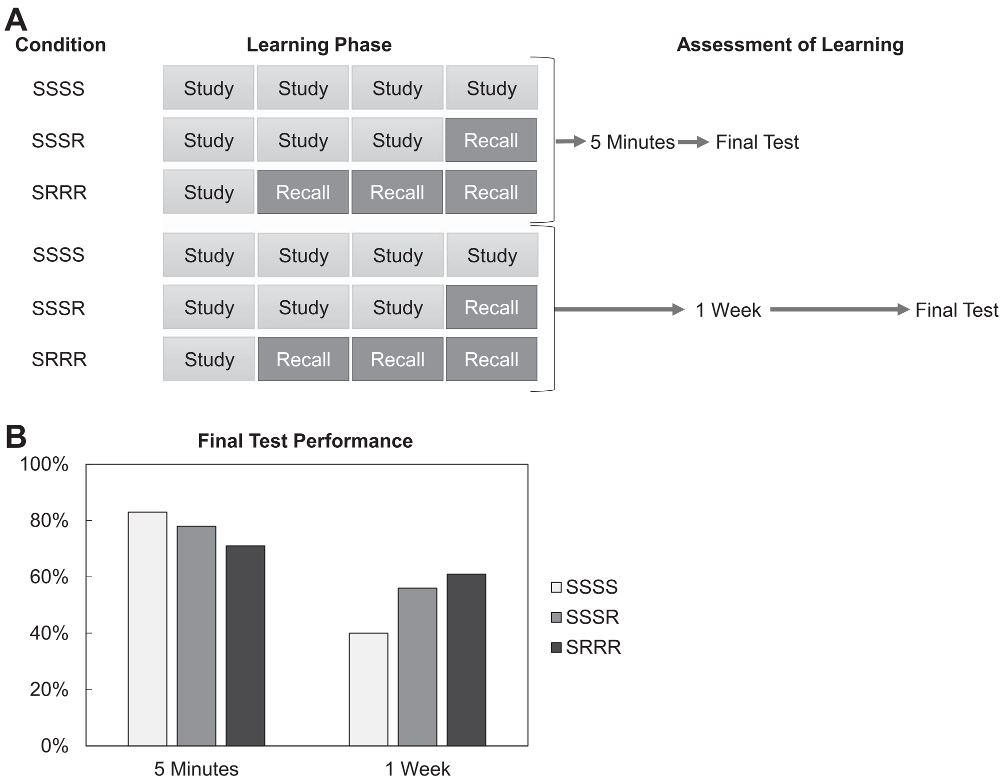

FIGURE 1. Illustration of Roediger and Karpicke (2006) experiment 2.[21] A, Experimental procedure. B, Percent correct on the final test for each of the experimental groups

used functional magnetic resonance imaging (fMRI) to examine how differences in regional brain activity may underlie the differences between repeated study and retrieval practice during learning. Wing et al[22] examined brain activity during learning, with participants being asked to learn weakly-associated word pairings (eg, study: TUSK—HORN, test: TUSK—?). After initially studying sets of word pairs while in the MRI scanner, half of the word pairs were shown next as a retrieval test (without feedback), with the remaining word pairs shown again for restudy. The word pairs were then presented in a study block again, followed by a second retrieval test or by restudy. Rather than being compared with a control group consisting of different participants, each participant had some word pairs that they studied four times (SSSS) and some alternating between study and recall (SRSR). Twenty-four hours later, the participants returned and had the final memory test (outside of the MRI scanner), which was the critical test of interest. Replicating and extending the behavior-only studies described in the classic research section, participants had better memory retrieval for the word pairings that were in the retrieval practice condition (SRSR) than those that they merely restudied (SSSS). Two particular brain regions (anterior cingulate cortex and inferior frontal gyrus) often associated with effortful learning were more involved in retrieval practice than in restudying. Another study conducted by Eriksson et al[23] used a procedure with two major differences: (1) There was no restudy-only condition, and (2) the procedure included up to eight memory tests (eight iterations of "SR"), but items were dropped from restudy (S trials) after successful recall. Nonetheless, these researchers also found that activation of one brain region (anterior cingulate cortex) was associated with more retrieval practice. Several other studies with other procedural differences have come to similar conclusions.

EXAMPLES OF CPD STUDIES INVOLVING RETRIEVAL PRACTICE

Often in conjunction with distributed practice, a strategy addressed in the first article of the series,[6] the authors found a variety of CPD studies of retrieval practice in the literature from different countries and involving multiple health care professions and specialties. Although not all studies that involved comparisons demonstrated a benefit of retrieval practice in outcomes measured (see, eg, McConnell et al, 2018),[24] the majority casts a favorable light on the strategy. In fact, a recent systematic review of test-enhanced learning (a common synonym for retrieval practice) in the health professions found that retrieval practice "…demonstrates consistent and robust effects across different health professions, learner levels [including CPD], [testing] formats, and learning outcomes."[2p.337] The systematic review authors recommend that health professions educators use tests, especially ones that require "production" (or recall) of information, in a repeated and spaced way, and that educators provide learners with feedback on test results.[2] Reflecting some diversity of published research to date, the authors of this article chose three examples to illustrate the strategy of retrieval practice in the context of CPD.

Kerfoot et al[25] evaluated an online, spaced, educational game among primary care clinicians to improve knowledge of hypertension management and blood pressure control of patients receiving care in eight US Veterans Affairs' medical centers. The intervention group received the "game," which consisted of emailed multiple-choice questions (with explanations) every three days for 52 weeks, with performance relative to peers offered to generate friendly competition. Until answered consecutively twice correctly, participants received repeat questions every 12 days (if incorrectly answered) or 24 days (if correctly answered). The control group received identical educational content through online posts.

Christopher et al[26] evaluated the first of a 5-year "stepwise skill reinforcement model" that included CPD as a way to improve important outcomes for Medicaid enrollees living in urban communities in Chicago. The CPD component included a needs assessment, which inquired about knowledge and skill with motivational interviewing, followed by a live CPD activity, an immediate assessment (commitment to change format with barriers anticipated), and another assessment 6 to 8 weeks later (about competence and performance). Participants (physicians and other professionals serving a variety of roles) then received five monthly "testlets" (each with a case scenario, multiple-choice question, immediate feedback, and access to additional information) to measure outcomes and to reinforce the application of skills to practice.

As a final example, Feldman et al[27] conducted a pragmatic randomized controlled trial to improve knowledge retention and self-reported learning behaviors of Canadian pediatricians attending a 4-day annual conference featuring 15 workshops. The control group consisted of participants attending a conference workshop only. The intervention group consisted of participants attending a conference workshop but also completing a pretest (multiple-choice without feedback) 1 week before the conference and a posttest (multiple-choice with feedback) 14 days after the conference.

RECOMMENDATIONS FOR CPD PARTICIPANTS AND PLANNERS

What Can CPD Participants Do to Leverage the Benefits of Retrieval Practice?

For CPD participants considering educational options to make significant improvements in knowledge, skill, attitude, and other important outcomes, taking advantage of a needs assessment, especially one that takes the form of a recall-style pretest, is likely superior to starting an educational activity without any advanced consideration of priority content. As a large-scale example of a pretest, the National Certification Corporation requires that nurses and nurse practitioners, who are beginning a new maintenance-of-certification cycle in a particular specialty or subspecialty, complete a 125-item assessment, the results of which drive an "individual education plan" (number of hours and focus of content) for that certification period.[28] Akin to taking a pretest, taking one or more posttests is a way to reinforce important information and to identify remaining gaps that might require additional effort. If spaced in time (≥1 day), each test requires a cycle that involves retrieval (accessing what is currently stored in long-term memory), encoding (considering information again in working memory), and consolidation (restoring information in long-term memory). This learning cycle is critical to mastery and memory (see Appendix, Supplemental Digital Content 1, http://links.lww.com/JCEHP/A113). If a pretest or posttest is not available for an activity, participants can identify a recent, representative case and reflect on what is known and unknown with respect to evidence. Discussing the case with a colleague to identify challenging questions would prepare one to learn more effectively through the activity or to follow-up with questions after an activity. Test questions might also be available through specialty societies. Even if such questions are recognition style, a participant can think about the answer before looking at response options, effectively searching long-term memory for the information.

WHAT CAN CPD PLANNERS DO TO LEVERAGE THE BENEFITS OF RETRIEVAL PRACTICE?

CPD planners can enhance the educational value of an activity by offering questions, ideally open-ended ones tied to challenging cases, as pretests and posttests. The expert recruited for the activity might identify or help to develop cases for these purposes and even construct responses that can serve as feedback to address inaccuracies and misperceptions. Another resource about cases for discussion and testing is *MedEd-PORTAL*, an open-access journal of teaching and learning resources in the health professions.[29] Published activities include educational materials and evaluation instruments. During the activity itself, such as a meeting, the expert-discussant could deliver an unfolding case rather than make a presentation, asking questions that would force participants to query their long-term memory for information. An unfolding case might be more engaging and interactive than a presentation, especially if the participants generated the case based on an adverse outcome. In 2012, the American Academy of Neurology (AAN) effectively used a pretest and multiple posttests to enhance learning associated with its annual conference.[30] The AAN's approach represents a combination of distributed practice and retrieval practice, but the optimal frequency of tests and the interval between them depends on a variety of factors.[5] Generally speaking, repeated retrieval attempts that are spaced are particularly effective.[8,9]

CONCLUSION

Retrieval practice involves using tests and related activities that challenge long-term memory to improve important educational outcomes in CPD. Cognitive psychology research in support of retrieval practice dates back over a century, and the field of neuroscience has begun to offer biological explanations that explain the strategy's effectiveness. Although people typically associate tests with high-stakes judgment, use of retrieval practice as a learning tool is appearing in the literature with increasing frequency, and retrieval practice's benefits have clear implications for participants and planners alike. Participants of CPD should seek activities that involve pretesting and posttesting, and planners should supplement CPD activities with questions or cases that force learners to examine their long-term memory throughout the activity. Planners of CPD activities should design activities with practice questions and cases that are meaningful components of the activity itself, along with preoptions and postoptions. Furthermore, rather than recruit experts to make presentations, educators planning CPD activities should use experts to engage and to interact with the audience, through unfolding case discussions that include challenging questions before, during, and after the activity proper. Retrieval practice can inform the collective imagination of participants and planners and, in so doing, improve the effectiveness of CPD activities.

Lessons for Practice

- Retrieval practice is an evidence-based strategy that supports learning and memory by requiring learners to scrutinize their long-term memory for important information and to undertake a challenge that can reinforce and extend expertise.
- Retrieval practice provides learners with an opportunity to test their memory for information not yet fully mastered and remembered, with opportunities for improvement that arise guiding additional CPD decisions and efforts.
- CPD planners and participants should use tests to enhance learning outcomes, considering open-ended and case-based questions to prepare, engage, and reinforce priority content.

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Science of Learning Strategy Series: Article 3, Interleaving

Thomas J. Van Hoof, MD, EdD; Megan A. Sumeracki, PhD; Christopher R. Madan, PhD

Abstract: Interleaving is an evidence-based, learning-science strategy that is relevant to the planning and implementation of continuing professional development (CPD). Mixing related but different areas of study forces the brain to reconcile the relationship between the areas while understanding each area well. By doing so, interleaving increases the likelihood of mastery and memory. Research from cognitive psychology and neuroscience provides the rationale for interleaving, and examples of its implementation in health profession education have begun to appear in the literature. If utilized appropriately, some common CPD interventions can leverage interleaving. Through increased understanding, CPD participants can benefit from interleaving by making more-informed educational choices, and CPD planners can benefit in efforts to improve educational activities.

Keywords: science of learning, interleaving, mixed practice, varied practice, random practice, scrambled practice, continuing education, continuing professional development

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ABOUT THE SCIENCE OF LEARNING STRATEGY SERIES

Consistent with a recent *Journal of Continuing Education in the Health Professions'* editorial by Kitto about informing the continuing professional development (CPD) imagination,[1] the emerging and interdisciplinary field of the science of learning, which concerns itself with how the brain learns and remembers important information, is a compelling but relatively unfamiliar field that stands to inspire CPD participants and planners to think about educational interventions differently. Moreover, the science of learning (learning science) has compiled evidence in support of a set of strategies[2–5] that can help CPD more effectively influence clinician knowledge, skill, attitude, competence, and even performance. The purpose of the series is to bring attention to evidence-based, learning-science strategies and to provide some background that might be helpful to CPD stakeholders considering the strategies. The first series' article on "distributed practice" focused on *when* one schedules learning sessions, which should be spread-out to allow participants more time and more opportunities to process important information.[6] The second series' article on "retrieval practice" focused on *how* one spends time while learning by testing oneself as a way to determine strengths and weaknesses of long-term memory for information that one previously strove to master.[7] Here, in this third article, the authors return to *when*, this time focusing on when to practice information within a given learning session. The authors accomplish this by describing "interleaving," a strategy also known by many terms, such as mixed, varied, random, and scrambled practice.

THE ESSENCE OF INTERLEAVING

The essence of interleaving is that when studying a particular subject during a single session, moving back and forth between different areas or between different principles, concepts, and procedures (ie, mixed practice, as in C-B-A-D-B-D-A-C) is better than the traditional approach of studying one topic in a sustained fashion (ie, blocked practice, as in A-A-B-B-C-C-D-D). Carey offers a simple explanation of interleaving as "... mixing related but distinct material during study."[8,p.163] Using board preparation for maintenance of certification in Internal Medicine as an example, rather than devoting one session each to answering oncology (O), hematology (H), and rheumatology (R) questions during a given week, interleaving would involve answering questions from all three areas each day. In other words, answering a random question set (eg, ORHRHOOHR on Monday, Wednesday, and Friday) leads to better long-term retention than solving a blocked set (eg, OOOOOOOOO on Monday, RRRRRRRRR on Wednesday, and HHHHHHHHH on Friday) in that interleaving forces one to consider the overlap and distinction between areas in addition to the mastery within each area. Whereas, with blocked practice, one gains mastery of an area without making critical comparisons between areas. Thus, interleaving forces the brain to reconcile the differences repeatedly, as one needs to do during a challenging test (eg, board recertification exam) and challenging application (eg, patient care). Unfortunately, interleaving typically *feels* more challenging to the learner, as it requires more effort than blocking; however, even with minimal background knowledge, learners still benefit

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Dr. Van Hoof: *Associate Professor, University of Connecticut School of Nursing, Storrs, and Associate Professor, Department of Community Medicine and Health Care, University of Connecticut School of Medicine, Farmington, CT.* ***Dr. Sumeracki:*** *Associate Professor, Department of Psychology, Rhode Island College, Providence, Rhode Island.* ***Dr. Madan:*** *Assistant Professor, School of Psychology, University of Nottingham, Nottingham, United Kingdom.*

Correspondence: *Thomas J. Van Hoof, MD, EdD, University of Connecticut, 231 Glenbrook Road, Unit 4026, Storrs, CT 06269-4026; e-mail: tom.vanhoof@uconn.edu*

more from interleaving. In addition to producing interleaving, this example also illustrates distributed practice, a separate but related learning-science strategy.[6]

CLASSIC RESEARCH UNDERLYING INTERLEAVING

While the research on distributed practice and retrieval practice has been ongoing for over a century,[6,7] research on interleaving is newer but promising nonetheless.[9] The positive benefits of interleaving were first demonstrated in the learning of motor skills. For example, in 1986, Goode and Magill[10] demonstrated that interleaved practice of badminton serves led to superior performance later, both with serves that were learned and serves that were new (serving from the other side of the court) compared with blocked practice. This effect has been demonstrated with other motor tasks as well (Bjork[11] for a review). At the turn of the 21st century, researchers began studying the effects of interleaving on learning in other domains. In one well-known example, Rohrer and Taylor[12] conducted an experiment in which college students learned how to compute volumes of four different geometric solids either in a blocked or interleaved order (Figure 1). The experiment took place across three sessions—two practice sessions and one assessment session—each spaced one week apart. During practice sessions in the blocked condition, students read a tutorial about how to solve one type of problem and then solved four practice problems of the same type. The procedure was repeated once for each type of problem, resulting in four tutorials and 16 practice problems (eg, AAAA-BBBB-CCCC-DDDD). In the interleaving condition, students read all four tutorials first, and then, they completed the same 16 practice problems but in a mixed order (eg, ACDB-CBAD-DABC-ADCB). During the second practice session, students repeated the procedure for their assigned condition with a new set of 16 problems. Finally, during the assessment, students solved eight novel problems. During practice, students performed nearly 30% better in the blocking condition (89%) compared with the interleaving condition (60%). If one were to stop here, one might think that interleaving is inferior to blocking, but on the assessment one week later, interleaving led to much better performance than did blocking (63% vs. 20%). Thus, interleaving produced durable learning but blocking did not. Further analyses indicated that while all students knew how to solve the problems, those in the blocked group struggled to recall the correct formula during the assessment, demonstrating that interleaving leads to a superior ability to discriminate among problems. Therefore, interleaving produced more durable learning and allows the learner to better differentiate among topics and apply the correct information, compared with blocking.

NEUROSCIENCE UNDERPINNINGS OF INTERLEAVING

Studies examining the neurobiological mechanisms that support interleaving are relatively sparse, although some studies of distributed practice were designed such that they can provide insight into interleaving as well. In a brain-imaging study, Zhao et al[13] asked participants to study words for a recognition memory test that would occur the next day. Each word

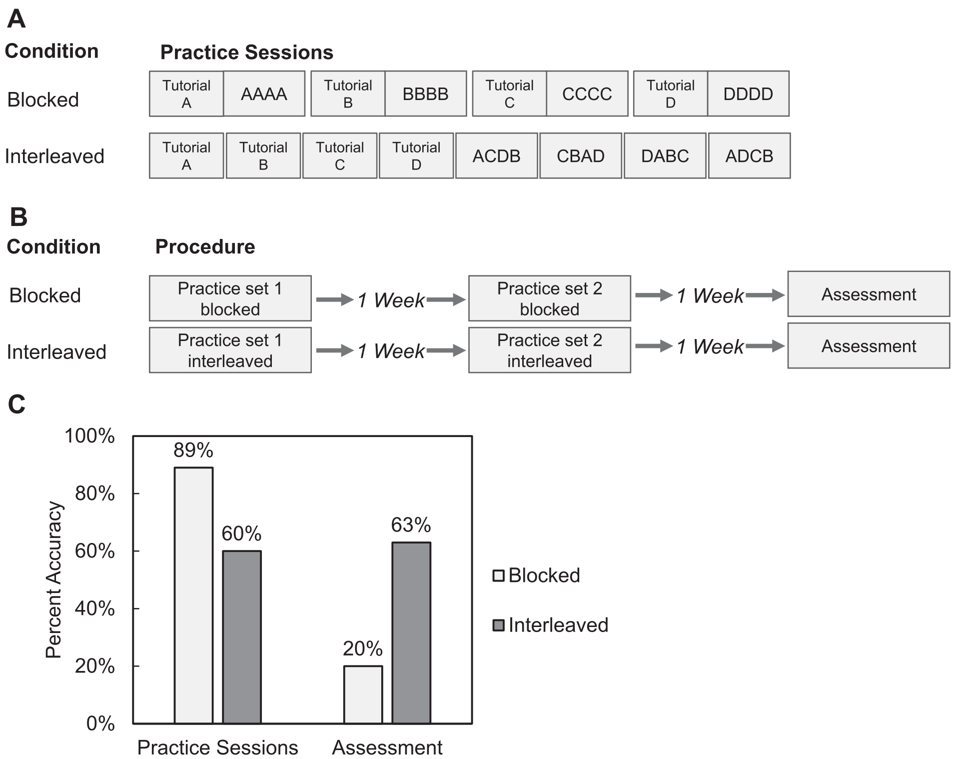

FIGURE 1. Illustration of Rohrer and Taylor (2007) experiment 2.[12] A, Example of the series of trials, with four types of tutorial and practice problems, in the experimental procedure. B, Outline of experimental procedure. C, Percent correct during practice sessions and the final assessment one week after practice for each of the experimental groups.

was presented three times. For half of the words, the three repetitions were blocked together, such that only one to three words were shown in-between the repetitions of that word. For the other half of the words, the presentations were further interleaved or spread-out, such that 25 to 35 words were presented between each occurrence. In the following day's memory test, performance was better for the words that were presented interleaved than those that were blocked. Of particular interest, words that were interleaved resulted in greater brain activation during study in a region associated with recognition memory (fusiform cortex) and regions associated with word-meaning interpretation (superior parietal lobule) (Figure 2).

This[13] and other brain-imaging studies[15,16] suggest that interleaved presentations reduce an effect known as "neural repetition suppression." When information is presented repeatedly, it is better remembered than if it were presented only once; however, people tend to pay less attention to the repetitions relative to novel information. This decrease in brain activity for repeated presentations is the neural repetition suppression. Using an interleaved approach attenuates this decrease in attention and decrease in other *deeper* processing of the content. These brain-imaging studies demonstrate that interleaving is not merely better than blocked presentations in behavioral results but also better in attenuating neural repetition suppression.

EXAMPLES OF CPD STUDIES INVOLVING INTERLEAVING

In the first two articles of the series, a number of CPD-specific examples of the learning strategies were available; however, with interleaving, the authors were unable to locate any published CPD studies. This could mean that CPD is not leveraging interleaving or that there simply are not published studies about the practice. The lack of CPD examples makes this article even more important as it serves to point to a (potentially) new way to improve learning in CPD and highlights the need for more research on the strategy in the CPD context. For illustration purposes, the authors describe a few interleaving studies that involved undergraduate psychology or medical students. While each study demonstrated support for the strategy, as in prior articles of the series, this section focuses on how experts incorporated interleaving rather than on the findings of the studies themselves.

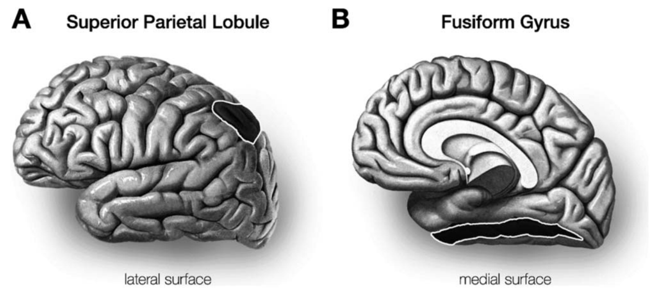

FIGURE 2. Brain regions associated with interleaved practice (adapted from Sobotto[14]). Superior parietal lobule, shown on a lateral surface. B, Fusiform gyrus, shown on a medial surface.

As one of three examples, Hatala et al[17] evaluated a 2-hour educational session on ECG diagnosis for first-year medical students, who had completed a 1-month cardiac rotation. The control and intervention groups both received an in-person presentation on the basics of ECG interpretation with two examples each of four cardiac conditions (ie, left ventricular hypertrophy [LVH], right ventricular hypertrophy [RVH], myocardial infarction [MI], and bundle branch block [BBB]); however, the two groups differed in time spent during the "practice" portion of the session. In the "noncontrastive" (noninterleaved) practice group, participants received four new examples of each condition (12 total) given in sequence (eg, LVH-LVH-LVH-RVH-RVH-RVH, etc). Whereas, in the "contrastive" (interleaved) practice group, the 12 new examples were "mixed" (eg, BBB-LVH-MI-RVH, etc).

As another example, Kulasegaram et al studied the impact of mixed versus blocked practice (and a context variable ignored here) on transfer (ie, "applying old knowledge to resolve new problems"[18],p.954) of three physiology principles (eg, fluid dynamics) among first-year undergraduate psychology students.[18] For each principle, students in the "blocked practice" group studied written explanations about each principle (ie, P1, P2, and P3) before applying the principle to two cases (eg, C1a and C1b for the cases associated with P1). Thus, the sequence was P1-C1a-C1b-P2-C2a-C2b-P3-C3a-C3b. In the "mixed practice" (interleaved) group, students read about all three principles first (ie, P1-P2-P3) before facing a set of six practice cases given in random order (eg, C3a-C1a-C3b-C1b-C2b-C2a).

As a third example, Rozenshtein et al[19] studied two groups of first and second year medical students experiencing two different approaches to learning x-ray interpretation. Both groups watched a 43-minute recorded presentation of 12 different radiographic patterns, the first of which was a normal chest x-ray, but the remaining 11 patterns reflected some type of pathology, such as pneumothorax (PT) and congestive heart failure (CHF). For the "massed" or blocked practice group, students saw six examples of each condition in 11 consecutive blocks (eg, PT-PT-PT-PT-PT-PT-CHF-CHF-CHF-CHF-CHF-CHF, etc), but in the interleaved group, students saw three blocks of 22 randomized images (mixing up the 11 pathologies), with each block containing only two examples of each condition.

RECOMMENDATIONS FOR CPD PARTICIPANTS AND PLANNERS

What Can CPD Participants Do to Leverage the Benefits of Interleaving?

For CPD *participants* considering educational options to make significant improvements in knowledge, skills, attitudes, and other important outcomes, selecting an educational activity that necessarily involves mixing related but distinct information (eg, diabetes knowledge updates and diabetes counseling skills) is a better strategy than one that focuses exclusively and repeatedly on only one area (eg, diabetes knowledge updates) during a session. Workshops that involve unfolding cases that require an integration of knowledge, skills, and attitudes (ie, competence development) often reflect interleaving. Interleaving forces the brain to shift gears between content areas, involving iterative cycles of encoding (considering information in working memory), consolidation (storing information in long-term memory), and retrieval (accessing ie, stored for additional consideration) that are critical to mastery and memory (see **Appendix, Supplemental Digital Content 1**, http://links.lww.com/JCEHP/A96). If activities available to participants do not offer a mixed approach, participants can transform them by supplementing them with other resources, such as taking a knowledge pretest or posttest to complement a skills workshop. Participants can also ask questions about previously covered or related information during a question and answer period. The increasing availability of practice tests supports interleaving, as do such activities as simulations and performance improvement projects, which often reflect a mix of related content each session.

What Can CPD Planners Do to Leverage the Benefits of Interleaving?

CPD *planners* can enhance the educational value of an activity by addressing multiple topic components (ie, knowledge, skills, and attitudes) or related areas (eg, cases with comorbidities) during a session, with the obvious advantage of longitudinal activities, which include prior and future sessions that lend themselves to reflection and preparation, respectively. Longitudinal educational meetings, such as grand rounds, can follow a consistent agenda that interleaves content, by including follow-up from prior sessions, such as discussion about commitments to change or posttests, and content from upcoming sessions, such as brief pretests or needs assessments. Some educational activities and formats, such as workshops, simulations, and performance improvement, are more consistent with interleaving than others, such as presentations.

CONCLUSION

Interleaving involves the mix of related but distinct information in study or practice that forces the brain to reconcile similarities and differences between information elements that are important to CPD outcomes. Cognitive psychology research in support of interleaving dates back decades, and the field of neuroscience has begun to offer biological explanations that explain the strategy's effectiveness. Although people typically associate mixing of practice to be challenging, interleaving is effective because it reflects a similarly challenging circumstance—patient care—in which health care professionals must access such information. Although research is necessary to understand and guide the use of interleaving in CPD, the strategy's benefits have current implications for participants and planners alike. Participants of CPD should seek activities that involve a mix of knowledge, skills, and attitudes in a single care area and/or a mix of related but distinct care areas in a given session or event. If such activities are not available, participants can supplement non-interleaved events with appropriate resources, which are increasingly common. Planners of CPD activities should design activities, ideally longitudinal, that require participants to reconcile different aspects of patient care within and across conditions, using formats and strategies that lend themselves to mixed practice. Interleaving can inform the collective imagination of participants and planners and, in so doing, improve the effectiveness of CPD activities.

Lessons for Practice

- Interleaving is an evidence-based strategy that supports learning and memory by requiring learners to alternate between different topics during a study or practice session.
- Interleaving provides CPD participants with an opportunity to prepare for circumstances (eg, exams and patient care) that require the ability to distinguish between related areas in addition to understanding each area deeply.
- CPD planners should utilize formats (eg, workshops and simulations) and structures (ie, agendas that require consideration of mixed content) that are consistent with interleaving.

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