Science of Learning Strategy Series: Article 3, Interleaving

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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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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

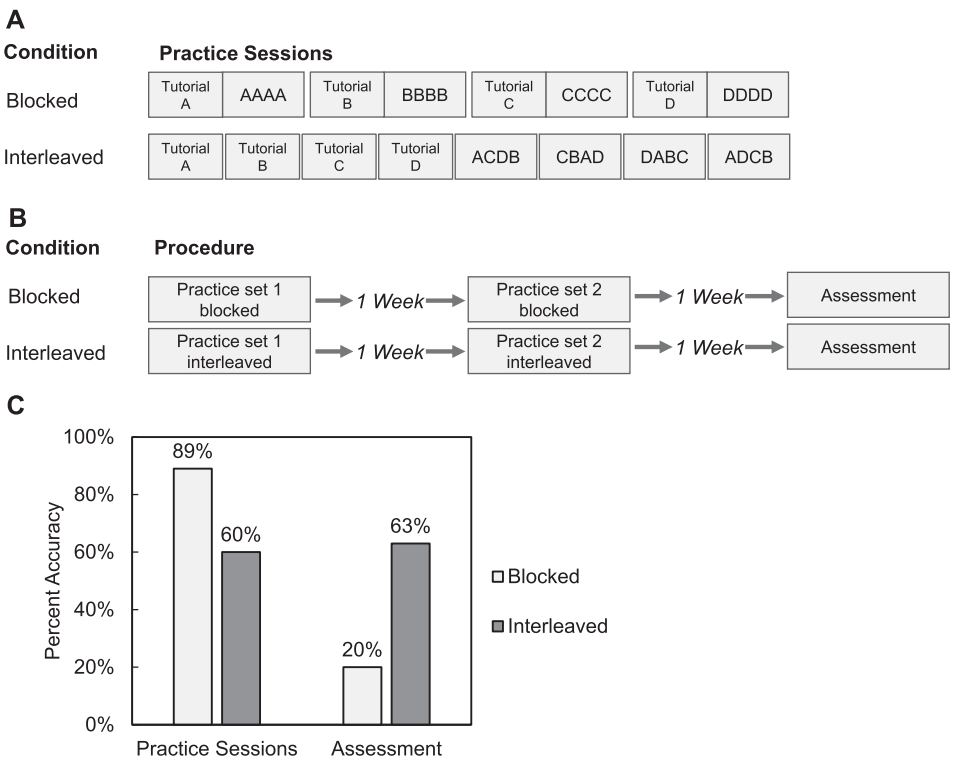

FIGURE 1. Illustration of Rohrer and Taylor (2007) experiment 2.[12] A, Example of the series of trials, with four types of tutorial and practice problems, in the experimental procedure. B, Outline of experimental procedure. C, Percent correct during practice sessions and the final assessment one week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

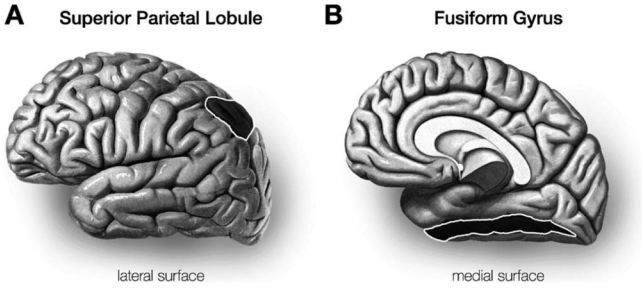

FIGURE 2. Brain regions associated with interleaved practice (adapted from Sobotto[14]). Superior parietal lobule, shown on a lateral surface. B, Fusiform gyrus, shown on a medial surface.

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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