

Interleaving Retrieval Practice Promotes Science LearningFaria Sana¹ & Veronica X. Yan²¹ Centre for Social Sciences, Athabasca University² Educational Psychology, The University of Texas at Austin

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The supplementary materials are appended to this document, starting on p. 20. Materials, data, and analysis markdown can be found at: <https://osf.io/aqng6/>

Abstract

Can interleaved retrieval practice enhance learning in classrooms? Across a four-week period, students ($N = 155$) took a weekly quiz in their science courses testing half of the concepts taught in that week. Questions on each quiz were either blocked by concept or interleaved with different concepts. A month after the final quiz, students were tested on the concepts covered in the four-week period. Replicating the retrieval practice effect, participants performed better on concepts that had been on blocked quizzes ($M = 54\%$, $SD = 28\%$) than on concepts not been quizzed ($M = 47\%$, $SD = 20\%$, $d = .30$). Interleaved quizzes led to even greater benefits, revealing an interleaving benefit: participants performed better on concepts that had been on interleaved quizzes ($M = 63\%$, $SD = 26\%$), than concepts that had been on blocked quizzes ($d = .35$). These results demonstrate a cost-effective strategy to promote classroom learning.

Keywords: interleaving; retrieval practice; classroom learning

Statement of Relevance

A common method for learning concepts is to repeatedly practice one concept at a time. Contrary to the research on interleaved practice, where multiple concepts are practiced in a mixed sequence, such blocked practice dominates instruction. Why? One reason may be due to a lack of comprehensive research on the interleaving effect. Scaling the practical benefits depends on demonstrating the benefits in real classroom settings across different grades and courses—this was the focus of the current study. We show that a 10-12 min weekly quiz can significantly enhance student learning on a delayed test. Importantly, if questions of different concepts on the quiz are ordered in an interleaved manner, it leads to even greater learning gains than if questions were blocked by concept. This implementation does not require additional teacher training, it is not time-intensive, and it is cost effective.

Interleaving Retrieval Practice Promotes Science Learning

Conceptual learning is the backbone of education. Yet, one of the challenges that science teachers face is promoting conceptual understanding, rather than simple memorization. That is, not only is the goal to have students learn definitions of new terms, but also to be able to understand the underlying idea, to abstract general principles, and to apply these principles across superficially different situations. For example, students in physics must not only learn the different types of circuits, they must also understand how a series circuit is similar to and different from a parallel circuit, and identify when each of these circuits applies in new problems.

In the present study, we leverage two principles from learning science—retrieval practice and interleaving—to examine whether a simple manipulation has the potential to increase conceptual understanding: brief, weekly quizzes with interleaved concepts. The benefits of retrieval practice are well-documented. In comparison to restudying, the act of effortfully bringing previously taught information to mind makes strengthens that learning, organizes knowledge, and makes it more easily retrievable and transferable in the future (Karpicke & Blunt, 2011; McDaniel et al., 2013; Roediger et al., 2011). Retrieval practice can take many forms (frequent quizzing, brain dumps, teaching others), and can easily be implemented both in and out of the classroom. In the present study, we focus on in-class quizzing.

Research on the interleaving effect is relatively recent, but studies have reliably demonstrated a striking and counterintuitive finding. Namely, that practicing problems (e.g., 1, 2, 3) of related concepts (e.g., a, b, c) in a mixed-up order ($a_1c_1b_1c_2b_2a_2b_3c_3a_3$; interleaved) can lead to better concept learning than practicing problems one concept at a time ($a_1a_2a_3b_1b_2b_3c_1c_2c_3$; blocked; Brunmair & Richter, 2019; Kang, 2016). One of the leading explanations for the

interleaving benefit is that when problems of different concepts are juxtaposed, as is the case with interleaved sequences, learners' attention is drawn to the features that help discriminate between the concepts (Carvalho & Goldstone, 2017; Kang & Pashler, 2012). In contrast, when problems are blocked by concept, there are fewer opportunities to notice the critical features that differ between concepts. The interleaving effect has been shown to be remarkably robust in controlled laboratory settings across a range of materials from perceptual categories (e.g., artists, butterflies, radiology) to cognitive concepts (e.g., statistics, clinical diagnoses, comma rules) and across a range of age groups (e.g., elementary school, college, medical school, older adults (Brunmair & Richter, 2019; Kang, 2016).

There have been only a handful of classroom studies on interleaved retrieval practice, all of which have focused on mathematics learning (Ostrow et al., 2015; Rohrer et al., 2014, 2015, 2020a). The largest classroom study to date is that of Rohrer and colleagues (2020a), showing a large benefit of interleaving (Cohen's $d = 0.83$) across 54 classrooms. In this study, seventh grade students completed interleaved or blocked worksheets across four months, followed by an interleaved review worksheet and then a final test one month later. However, interleaving was manipulated together with spacing. That is, not only were practice problems of a given concept interleaved with the practice problems of other concepts, but they were also distributed across every worksheet (8 worksheets across 103 days). In contrast, in the comparison group, practice problems of a given concept were both blocked (practiced consecutively, without any other intervening concept) and massed (practiced in just one worksheet, on a single day within the 103-day timeframe). This confound poses a potential theoretical problem—did improved learning occur due to the mixing of different concepts, the spacing of problems from the same concept across months, or both? Moreover, it is unclear whether effects found for mathematics will

generalize to science concept learning. In each of these studies, the target skill was mathematics problem solving, which consists of both conceptual and procedural components—hence, benefits could arise from either greater practice in using formulae, deepening conceptual understanding, or a combination of both.

Clearly, interleaved retrieval practice is a promising strategy to promote learning. And yet, blocked instruction dominates academic programs and materials (Rohrer et al, 2020b). Although students often receive opportunities to practice applying what they learn, these opportunities often do not involve retrieval (in the case of homework where they can refer to their notes) and are often blocked (i.e., practice on the one concept that was just learned), or are treated as high-stakes summative assessments (e.g., final exams) rather than low-stakes, formative, learning opportunities. What are some barriers in scaling interleaved retrieval practice from the lab to the classroom? First, there is a lack of empirical classroom-based evidence demonstrating the benefit of the interleaving, beyond mathematics problem-solving, and separate from the spacing. Second, given the dearth of classroom studies, there is also a lack of evidence for the impact of interleaved retrieval practice across educationally-relevant retention intervals. Hence, in the present experiment, we examined whether interleaved practice of science concepts through brief end-of-week in-class quizzes can deepen and sustain students' conceptual learning.

Method

Participants

We recruited eight science classrooms ($N = 155$ students), ranging from 9th to 12th grade from a mid-sized Canadian public high school in southern Ontario. Students were given a \$3 Tim Hortons gift card if they completed the consent form, regardless of whether they chose to participate in the study or not. The consent rate (assent obtained from both students and their

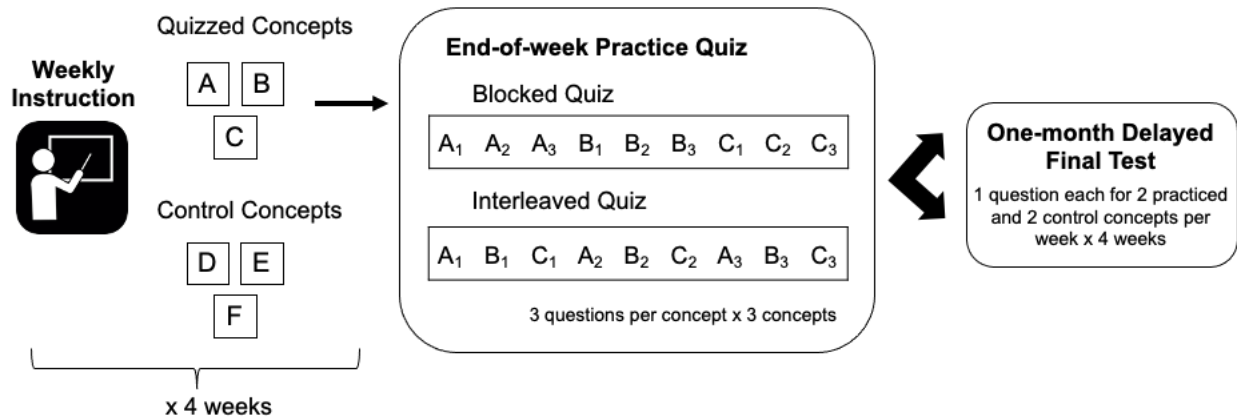
guardians) was 100%. The school was unable to provide any other demographic information. However, according to 2016 Canadian Census data for the town, English is the mother tongue language of roughly 61% of the town's population (Statistics Canada, 2017). Teachers were recruited following a workshop that provided an overview of the evidence-based strategies that promote student learning. Six teachers who taught Science, Biology, Chemistry, and Physics agreed to participate in the study, which was conducted mid-semester in the winter term of 2019. Each teacher was given a \$500 CAD honorarium. We implemented the study in as many classrooms as we could recruit after the workshop, and power analyses using G*Power 3.1 revealed that we would be powered to detect a conservative, medium effect size of $d = 0.40$ at alpha level of 0.05 with 80% power with only 52 participants (given a within-subjects design).

Design

The study followed a repeated measures design with three conditions: concepts that were practiced blocked, concepts that were interleaved, or concepts that were not practiced (control). Figure 1 illustrates the design of the study. The initial quizzing phase spanned four weeks in which the concepts taught in each week were assigned to the practiced or non-practiced condition. Across weeks, the quizzes alternated between presenting the practice questions blocked by concept or interleaved. Classrooms were randomly assigned to either start with a blocked quiz on week 1 or an interleaved quiz on week 1. There were two teachers who both taught two sections of the same class (9th grade science and 11th grade biology). For these two pairs of sections, one section of each pair was randomly assigned to start with a blocked quiz and the other was assigned to start with an interleaved quiz. A final test occurred one month after the end of the four-week quizzing phase.

Figure 1

The general design of the study.



Materials

All questions were created by two graduate students who had recently received their teaching accreditation in science and who were serving as substitute teachers in a similar school district teaching the same curriculum. These questions were then vetted by the teacher of each class, to ensure that they were conceptually accurate and were written appropriately for their student level. Questions were randomly selected to be either on the weekly quiz or the final test. All quizzes and the final test were administered on pen-and-paper and were graded by a research assistant who was blind to the study hypotheses and manipulations. Following open science practices, materials, data and analyses can be accessed at: <https://osf.io/aqng6/>

Weekly Quizzes

As each teacher taught a different class and hence covered different material, we created four end-of-week multiple-choice quizzes for each teacher. For each of the four target weeks during the quizzing period (March 25, 2019-April 18, 2019), teachers identified at least six concepts that students typically find confusing. Three of these concepts were randomly selected to appear on the end-of-week quiz (three questions per concept). The questions were ordered such that they were blocked by concept or interleaved so that no two questions on the same

concept were consecutive. For half of the classes, the concepts on quizzes 1 and 3 were interleaved and the concepts on quizzes 2 and 4 were blocked. For the other half of classes, the concepts on quizzes 1 and 3 were blocked and the concepts on quizzes 2 and 4 were interleaved.

Final Test

To keep the length of this final test manageable, instead of testing every concept taught in the four week quizzing period, we randomly selected four concepts from each week—two that were on the quiz (practiced) and two that were not (control). Hence, the final test consisted of 16 questions, which could be classified into three conditions: 8 questions from the control condition, 4 questions that appeared on a blocked quiz, and 4 questions that appeared on an interleaved quiz.

Procedure

For four weeks, students were given these quizzes on the last class day of each week (usually Friday; occasionally Thursday if it was the last class day of the week, for example, on the week of Good Friday). Test packets were delivered to the teachers either the day before or the morning of test administration. In any given week, all the students in one class received the same quiz. Students had 10-12 minutes to complete the quiz each week and were encouraged to answer all questions in the order in which they were presented. While the intent was for teachers to be blind to the sequence conditions, it was easy to guess the condition based on the question order on a quiz. One month after the fourth practice quiz, students were given a surprise final test and were given 20 minutes to complete it.

We requested the teachers to not provide any aid to the students while they were completing the quizzes or the test, and to not give feedback to the students after the quizzes were completed and collected.

Results

First, we examined whether the sequencing of the practice quizzes yielded different levels of performance on the quizzes themselves. The left side of Figure 2 shows the overall performance on blocked and interleaved quizzes; Table 1 lists the details by classroom. To account for the nested nature of the data (different concepts were taught within each course-grade combination), we conducted a linear mixed effects regression analysis, predicting practice quiz score from condition (blocked, interleaved), including individual ID and concepts nested within course-grade entered as random effects¹ (see Table S1 for full results summary). This analysis revealed that the scores on the interleaved quizzes were significantly lower than those of the blocked quizzes, $b = -.07$, $SE = .02$, $t(819.76) = -3.43$, $p < .001$, Cohen's $d = 0.21$. In other words, the interleaved practice quizzes were harder than the blocked practice quizzes.

More importantly, we examined whether there were significant differences between the three conditions on the final test—the mean percentage scores on the final test by condition are represented in the right side of Figure 2 and detailed by classroom in Table 1. We conducted a linear mixed effects regression analysis predicting final test score from condition (control, blocked quiz, interleaved quiz), with individual ID and concepts nested within course-grade entered as random effects. The blocked quiz condition was set as the reference condition (see Table S2 for full results summary). Results revealed two critical findings: First, the blocked quiz condition led to significantly better final test performance than the no-quiz, control condition, $b = -.09$, $SE = .03$, $t(119.07) = -2.66$, $p = .009$, Cohen's $d = 0.30$. This result replicates the retrieval practice effect. Second, the interleaved quiz condition led to significantly better final test

¹ There was only one set of missing data—quiz #4 (interleaved) for one of the two grade 11 biology classrooms.

performance than the blocked quiz condition, $b = .08$, $SE = .03$, $t(602.67) = 2.68$, $p = .008$, Cohen's $d = 0.35$. This result reveals an additional benefit of interleaving on top of retrieval practice.

Figure 2

The Mean Performance on Blocked and Interleaved Quizzes on the Left and the Mean Performance on the Final Test by Condition (Control, Blocked, Interleaved) on the Ride Side

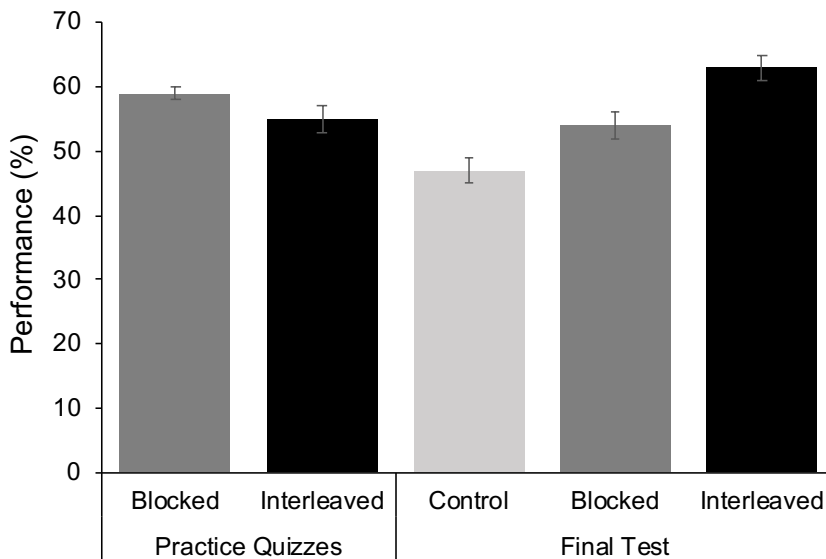


Table 1

Mean (and Standard Deviation) Percentage Performance on the Weekly Quizzes and Final Test, by Class and Sequence Condition

Classroom	Subject (Grade level)	Weekly Practice Quiz		One-Month Delayed Final Test		
		Blocked	Interleaved	Control	Blocked	Interleaved
1	Science (G9)*	58 (19)	57 (18)	48 (18)	55 (35)	59 (25)
2	Science (G9)	66 (16)	48 (17)	50 (25)	55 (19)	67 (29)
3	Science (G10)	56 (14)	34 (14)	39 (18)	46 (24)	53 (21)
4	Biology (G11)*	69 (13)	51 (25)	45 (19)	50 (25)	59 (25)
5	Biology (G11)	35 (14)	49 (9)	38 (22)	44 (37)	48 (31)
6	Physics (G11)	57 (14)	57 (11)	45 (18)	59 (22)	66 (22)
7	Chemistry (G12)	68 (16)	70 (18)	56 (17)	61 (24)	78 (22)
8	Physics (G12)	62 (11)	76 (12)	54 (19)	63 (28)	75 (25)
Overall		59 (18)	55 (20)	47 (20)	54 (28)	63 (26)

Note. G9 = Grade 9, G10 = Grade 10, G11 = Grade 11, G12 = Grade 12. Classes marked with * reflect two sections taught by different teachers, where content assignment to the blocked or interleaved condition in each week was counterbalanced between sections.

Discussion

The current study investigated the long-term effects of interleaved retrieval practice in Grades 9-12 science classrooms. We found that on a surprise test administered one month after the last practice quiz, students performed better on concepts that were quizzed compared to concepts that had not been quizzed. This finding is consistent with previous studies that show the learning benefits of retrieval practice (Yang et al., 2021). We also found that students performed better on concepts that appeared in the interleaved quizzes, where the order of the questions was mixed up, than on concepts that appeared in the blocked quizzes, where questions were organized by concept.

Only some studies have previously examined interleaved retrieval practice in classrooms, most of which include students completing weekly *cumulative* math assignments (i.e., assignments that assess concepts covered both in the current and in previous weeks), which combines interleaving and spacing benefits. In the present study, we manipulated interleaving without also manipulating spacing to show that interleaving alone can enhance student learning.

Our study builds on prior studies in two ways. First, we separate interleaving from spacing by only quizzing students once on the concepts taught in each week. Second, most of the prior studies have focused on either content that has not yet been taught by teachers (Zielger & Stern, 2014) or is not currently being taught by the teacher (e.g., concepts learned in a prior semester or in a prior school year; Rohrer et al., 2014). In our study, the weekly quizzes were administered as the students were learning the concepts in class. In other words, the weekly quizzes were taking place in the context of other rich learning activities and study behaviors (e.g., in-class lessons, discussions, homework assignments). On one hand, this context reduced experimenter control because students were being exposed to the concepts repeatedly outside of

our quizzes. On the other hand, it makes the results of our study even more surprising and meaningful. These quizzes added only 10-12 min of class time each week and yet led to sizable and sustained learning benefits a month later. In fact, the potential benefit of setting aside only 10-12 min per week is particularly striking when one considers the large difference between the interleaved retrieval practice condition (63%) and the control condition (47%; a large effect size of $d = 0.71$).

Although this study addresses a gap in the literature, it has limitations. Given that the content on the quizzes was core to the course, we could not control how the concepts were discussed and practiced outside of our quizzes. In fact, teachers often reviewed previous concepts across subsequent weeks in their own lessons, and encouraged students to space out their study sessions. It is possible that students changed how they studied following interleaved quizzes because interleaving often feels disfluent and difficult compared to blocking (e.g., Yan et al., 2016). If a student interpreted this disfluency as insufficient learning, they could have engaged in compensatory studying. To test this hypothesis, we calculated the difference between interleaved and blocked quiz scores for each student, and then examined whether this difference score significantly moderated the interleaving benefit on the final test. If this hypothesis is supported, then we would expect that students who experienced larger blocking benefits on the practice quiz should have larger interleaving benefits on the final test due to engaging in compensatory studying. Our analysis, however, showed that the difference between blocked and interleaved quizzes had no bearing on final test performance (see Supplemental Materials Table S3 for details).

Another limitation is that we could not randomly assign concepts at the student level; rather, randomization of concepts to condition occurred on a weekly basis for each course-grade

combination. There were two pairs of classrooms, however, in which we could counterbalance assignment of concepts to interleaved or blocked quiz conditions: Grade 9 Science and Grade 11 Biology. Although the two classes in each pairing were taught by different teachers, the curriculum and the concepts covered in each class were identical. Hence, in a given week, when one classroom from the pair was assigned a blocked quiz, the other classroom from the pair was assigned an interleaved quiz. When we restrict our analyses to just these four classrooms ($n = 72$), we find the same pattern with a similar effect size to that of the larger sample: the final test performance for the interleaved concepts ($M = 58\%$, $SD = 28\%$) was higher than that of the blocked concepts ($M = 51\%$, $SD = 30\%$), Cohen's $d = .27$. Moreover, given the sheer number of concepts in each class, it is unlikely that the concepts in one condition were systematically different from the concepts in the other conditions. Indeed, the heterogeneity of the grade levels, the courses, and the concepts in our study can be perceived as a strength—the interleaving benefit is robust across all these differences.

The current study offers a solution to the practical question of how interleaving could be incorporated into classroom practice. Interleaving instruction can feel disorganized and chaotic, and may require a significant time investment to restructure curriculum. However, rather than interleaving *instruction*, we propose that interleaving *practice* may be an easier, yet highly effective, solution. Future research in classrooms should focus on moving beyond the dichotomy of interleaved versus blocked practice. Given that blocking has also been shown to have benefits for directing learners to within-concept examples (e.g., in lab experiments with artificial materials, Carvalho & Goldstone, 2017) and to provide support for novice learners (e.g., in motor skills learning, Wulf & Shea, 2002), future research should examine ways of optimizing interleaving dosage for different learners. For example, learners with lower prior knowledge may

require more blocked practice before moving on to interleaved practice (but see Ostrow et al., 2015 who found greater interleaving benefits for low-skilled learners).

These findings also add to the growing body of research showing the potential for learning science to impact educational practices and education outcomes. In a recent review, Kraft (2020) found that the median effect size of educational interventions using narrow measures of achievement outcomes (i.e., researcher-designed tests that are aligned with the treatment, as we have in our design) was $d = 0.17$. Our effect size of $d = 0.71$ (between the control and interleaved retrieval practice conditions) is considerably larger. There is still work to be done to further understand whether interleaved retrieval practice can affect broad achievement measures (e.g., standardized exams) and effects on much more heterogeneous samples. However, the data is highly promising, especially in light of the fact that the intervention is simple to implement: it does not require additional teacher training, it is not time-intensive, and it is cost effective. Teachers likely have existing assignments and practice problems developed for their own classes or have access to resources they can use (e.g., test banks, end-of-chapter practice problems, resources provided by publishers); the difference would be to break up longer exams into more frequent, shorter quizzes, and to change the sequence in which questions are assigned, making sure that concepts are interleaved rather than blocked.

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Supplementary Materials

Table S1

Summary of [Un]standardized Regression, Predicting Practice Quiz Performance

Fixed	<i>b</i>	SE	<i>df</i>	<i>t</i>	<i>p</i>
Intercept	.61	.04	5.64	14.70	<.001
Condition: Interleaved	-.07	.02	819.76	-3.43	<.001
Random					
ID	.007				
Concept: CourseGrade	.024				
CourseGrade	.006				
Residual	.066				
N of students	155				
N of Concept: CourseGrade	48				
N of CourseGrade	6				

Note. Reference condition: blocked.

Table S2

Summary of [Un]standardized Regression, Predicting Final Test Performance

Variable	<i>b</i>	SE	<i>df</i>	<i>t</i>	<i>p</i>
Intercept	.56	.04	10.23	14.68	< .001
Condition: Control	-.09	.03	119.07	-2.66	.009
Condition: Interleaved	.08	.03	602.67	2.68	.008
Random					
ID	.009				
Concept: CourseGrade	.010				
CourseGrade	.004				
Residual	.223				
N of students	155				
N of Concept: CourseGrade	96				
N of CourseGrade	6				

Note. Schedule reference condition: blocked.

Table S3

Summary of [Un]Standardized Regression, Predicting Final Test Performance from Condition and Difference in Performance from Blocked and Interleaved Quizzes

Variable	<i>b</i>	SE	<i>df</i>	<i>t</i>	<i>p</i>
Intercept	.56	.04	9.09	14.05	< .001
Condition: Control	-.08	.03	118.7	-2.66	.009
Condition: Interleaved	.08	.03	599.3	2.67	.008
Practice Quiz Difference (standardized)	-.007	.02	947.2	-0.33	.741
Control* Practice Quiz Difference	-.008	.02	2035	-.33	.739
Interleaved*Practice Quiz Difference	-.003	.03	1603	-.13	.898
Random					
ID	.009				
Concept: CourseGrade	.010				
CourseGrade	.005				
Residual	.224				
N of students	155				
N of Concept: CourseGrade	96				
N of CourseGrade	6				

Note. Schedule reference condition: blocked. Practice quiz difference score calculated as interleaved - blocked.