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Can the Spacing Effect Improve the Effectiveness of a Math Intervention Course for Engineering Students?

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It is critical for students in science, technology, engineering, and math (STEM) majors to retain and transfer mathematical knowledge from one course to the next. Although mastery of many domains of mathematical knowledge depends on previous knowledge, students often fail to retain what they have learned in one class when they advance to the next. Research in cognitive psychology suggests that poor retention is a consequence of students' study practices and instructors' pedagogical techniques.

Nearly 30 years ago, Edge and Friedberg[1] discussed the challenges of a first college calculus course. Calculus continues to pose a challenge for many STEM students, with many classes still suffering from pass rates below 50%. In fact, Beanland, a prominent engineering educator, claims "the biggest factor contributing to the failure of engineering students is inadequate competence in mathematics"[2]. Suresh[3] reports that roughly 50% of engineering majors change majors or drop out in the first or second year, due in part to performance in mathematics, as reported by Felder et al.[4]. Recently, Pearson and Miller[5] found that nearly one-third of students who enter an engineering program fail to complete it, and they also found that the two strongest predictors of completion of a baccalaureate in engineering were completion of a calculus course in high school and the number of college calculus courses taken. This finding suggests that mathematics performance is critical for collegiate success in engineering. The problem is not limited to engineering majors. Kajander and Lovric[6] posit that the transition challenge from secondary to college education in mathematics is the most difficult of all subject areas. Their research suggests that students' knowledge of functions and algebra was lacking at the beginning of their college careers, and that many students in high school had developed only "surface learning" of mathematics.

It is likely that retention of previously acquired mathematical information is critical for subsequent development in the domain. Recent studies in cognitive psychology have shown that study and testing techniques that increase retention also increase people's ability to make conceptual inferences about related topics[14-16]. In other words, techniques that increase retention not only solidify existing knowledge but increase people's ability to derive new knowledge. Related to this, in the domain of mathematics, Richland et al.[13] suggested that many students graduating from K-12 systems lack flexible, conceptual mathematical knowledge. We theorize that this lack may owe in part to poor retention of previously acquired information. Consequently, it is important to consider how people successfully achieve long-term retention of information.

Research in cognitive psychology has shown that long-term retention of information depends on what individuals do with the information subsequent to initial exposure. The act of retrieving a piece of information from memory increases the likelihood that the information will be retained at a later time[8, 9]. This is known as the *retrieval practice effect*. In contrast, restudying information, without retrieving it from memory, often has surprisingly little impact on long-term retention. College students, however, report engaging in more restudy than self-initiated retrieval in their academic careers[11]. Instructor-initiated practices that promote retrieval increase retention and hence academic performance in classroom settings[17-19]. For example, Lyle and Crawford[18] found that students who took a short quiz covering the main points at the end of every lecture in a statistics course earned significantly higher grades on exams than did students who did not take the quizzes.

Critically, the positive effect of retrieval on retention is maximized by introducing intervals of time between retrieval attempts[10, 20]. That is, any given number of retrievals will have a greater impact on retention if the retrievals occur non-consecutively versus consecutively. This is called the *spacing effect* in reference to the spacing out of retrieval attempts over time. Relevant to the current research, spaced retrieval has been shown to increase retention of mathematics knowledge in the laboratory[22, 23], but we are not aware of any systematic study of the value of spaced retrieval in an actual mathematics course of any type.

It is likely that many college students do not spontaneously implement spacing in their own study practices because research suggests that people are not cognizant of the value of spacing[10, 21]. In general, research shows that most people do not understand how human memory works. Most laypeople disagree with expert characterizations of forgetting[7], and apparently do not appreciate that the majority of encoded information is rapidly forgotten if nothing is done to prevent it. Furthermore, people do not know how to prevent forgetting, or, in other words, how to achieve long-term retention of information. Students report that rereading is their top study strategy, even though rereading actually has little or no impact on the long-term retention of information, and students report relatively little self-initiated retrieval[12].

Just as students' ignorance of the basic principles of memory may undermine their study habits, so too may educators' ignorance lead them to utilize sub-optimal pedagogical techniques. Instructors often design classes in which it is possible for students to do all the homework problems for a given topic more or less consecutively (so-called massing), and then take the one and only exam covering the topic shortly thereafter. This approach minimizes spaced retrieval, depriving students of spacing's mnemonic benefits.

In the current research, we implemented a spaced retrieval intervention in a precalculus course for freshman engineering students at the University of Louisville (*Introductory Calculus for Engineers*). Specifically, we assigned some students in the class to receive quiz questions in massed fashion and others to receive those same questions in spaced fashion. The presentation of questions in massed fashion is considered the control condition because massed presentation has been used in previous iterations of the course and is presumably common in many other engineering mathematics courses at other universities, as well. In the control condition, after a given topic (or learning objective) had been taught in class, three questions assessing mastery of the objective were presented on a weekly quiz. Hence, students in this condition were required to retrieve the information necessary to answer the three questions in temporal proximity, with little spacing between retrievals. In contrast, in the experimental condition, in which spaced retrieval was implemented, the three questions were distributed across three different quizzes. The first question appeared on the first weekly quiz following presentation of the objective in class, but the second and third questions were included on subsequent quizzes, with temporal intervals (or spacing) between them.

We predicted that spaced retrieval in the experimental condition would increase retention of objective-specific information relative to massed retrieval in the control condition. To test for differential retention in the two conditions, we examined performance on the cumulative final exam in *Introductory Calculus for Engineers*. The final exam assessed mastery of learning objectives presented throughout the course of the semester, requiring retention of information presented weeks or months previous. We expected that students would exhibit greater mastery of learning objectives when retrieval practice on quizzes was spaced versus massed. More information about our research design is provided under Study Overview and in the Method.

Study Overview

In the current study, we manipulated spacing of retrieval practice for target objectives in *Introductory Calculus for Engineers*. Specifically, we manipulated the spacing of questions on weekly quizzes. Answering quiz questions is a form of retrieval practice. Spacing was manipulated in a hybrid between- and within-subjects design. In a control condition, all quiz questions assessing mastery of target objectives were presented in a massed format. On the quiz immediately following introduction of a given target objective, subjects were assigned to answer all the questions targeting that objective. Quiz questions for each and every target objective were massed in this fashion in the control condition. In contrast, in the experimental condition, only half of the target objectives were quizzed in massed fashion. For the other half of the target objectives, retrieval practice on quizzes was spaced. On the quiz immediately following introduction of a given target objective, subjects were assigned to answer only one question targeting that objective. Additional questions targeting that same objective were included on subsequent quizzes, as described in more detail under Method and as depicted graphically in Table 1. Hence, the experimental condition allowed for a within-subjects comparison of massed versus spaced objectives (i.e., would individuals demonstrate greater mastery of objectives that were spaced for those individuals, compared to those that were massed?). We were additionally capable of assessing the effect of spacing between-subjects by contrasting mastery of spaced objectives in the experimental condition with massed objectives in the control condition (i.e., would the students for whom some objectives were spaced demonstrate greater mastery of those objectives than the students for whom those same objectives were massed?).

Method

Subjects

Subjects were students enrolled in *Introductory Calculus for Engineers*. Before the semester began, subjects were pseudo-randomly assigned to the experimental and control conditions, with the constraint that the conditions did not significantly differ on racial composition, gender composition, mean ACT Math score, or mean high school grade point average (GPA). Initially, 58 students were assigned to each condition. During the course of the semester, 22 students withdrew from the class. Of these students, 14 had been assigned to the experimental condition, and eight to the control condition. The withdrawal rate in the two conditions did not differ significantly, $\chi^2(1) = 1.402$, $p = .24$. Data from subjects who withdrew were not included in any analyses. Table 2 shows the demographic and academic characteristics for each condition based on those subjects who completed the class. The two conditions did not differ significantly on any characteristic, all *p*s > .83 for tests of between-condition differences.

Materials

Introductory Calculus for Engineers contains a total of 193 learning objectives, identified prior to the commencement of the present study. From these, the second and third authors selected 48 as target objectives in this research. The authors selected objectives they deemed especially critical for success in the course. Example target objectives are presented in Table 3.

Three questions assessing mastery of each target objective were drawn from quizzes and tests administered in previous iterations of *Introductory Calculus for Engineers*. Some adjustments to the questions were made based on the authors' expertise to ensure that all questions were of comparable difficulty. The adjustment process was also informed by objective data yielded by MyMathLab® in previous semesters (see below).

Quizzes were created by combining questions covering different target objectives. In the control condition, each quiz contained three questions covering each of six target objectives introduced to students in the preceding week, for a total of 18 questions covering target objectives. There were up to eight additional questions on each quiz covering objectives not targeted by this study. Each quiz has a corresponding companion study plan assignment. The companion study plan assignment included both target and nontarget objectives. The study plan assignment presented students with practice questions and a "quiz me" activity for each objective.

In the experimental condition, questions covering three of the six target objectives presented in the preceding week were massed, as in the control condition. Questions covering the remaining three target objectives were spaced according to the following scheme (depicted graphically in Table 1). One question appeared on the first quiz following presentation of the objective in class. A second question appeared on the subsequent quiz, approximately one week after initial presentation of the objective. The next quiz in sequence did not contain any questions covering these objectives but the following one, approximately three weeks after initial presentation of the objective, contained a third and final question. Critically, assignment of objectives and their corresponding questions to massing or spacing was counterbalanced across subjects in the experimental condition. Due to the spacing of some objectives, quiz length in the experimental condition ranged from 15-18 questions.

In both the control and experimental conditions, the number of quizzes was 12, although only the first 11 contained questions covering target objectives.

All quizzes and study plan assignments were administered via an online system called MyMathLab®, which is an interactive learning system developed and maintained by the Pearson textbook publishing company. MyMathLab® includes an electronic copy of the course textbook, and additional types of media that provide course content such as videos, animations, presentation slides, and projects. MyMathLab® also includes the MathXL® engine which can present students with a problem similar to those in the exercise sets at the end of each section in the textbook. Most problems are algorithmic, meaning that each time the question is presented it is slightly different (e.g., using different numbers). The MathXL engine allows for traditional multiple-choice answers, but it is also able to parse mathematical expressions, allowing problems that ask students to enter: 1) exact numerical answers that include decimals, fractions, radicals, exponents as well as symbols like π, 2) expressions such as the equation of line, or even 3) other types of mathematical notation such as intervals and sets. MathXL grades students' answers and records these grades in an online gradebook. The MathXL engine also includes learning aids with each problem. Learning aids include: links to relevant sections in the textbook, "show me an example", and "help me solve this" each of which steps students through a solution. Instructors build problem sets by just selecting different problems using a graphical wizard in the web interface. For *Introductory Calculus,* the ebook used was Precalculus: A Right Triangle Approach by Kirk Trigsted.

The cumulative final exam was the same for all subjects and was administered in a proctored setting via MyMathLab®, with a two-hour limit. The test included one question covering most target objectives, but included up to three for some objectives. When multiple questions covered the same objective, proportion correct for those questions was calculated to represent a student's mastery of the objective. Proportion correct was also used when there were multiple steps involved in a question (e.g., finding the quotient and remainder in polynomial long division, or finding the value of the six trigonometric functions given a point on the unit circle), and a student completed only part of it correctly. Also, where appropriate, un-simplified answers were scored as 95% correct.

Procedure

The syllabus for Introductory Calculus for Engineers informed students of the study and explained that they could opt not to have their performance data included in analyses by contacting their instructor. No students chose to have their data excluded. The study description informed the students that they were subjects in a spaced retrieval study, which spaced retrieval study, which would require the authors to collect information related to their course work (e.g., time and date of work, scores), and who to contact if they wished to not participate. There was no information given to the students regarding the hypotheses. The class was conducted similarly to the previous semester when it was taught. The class followed the emporium model (http://www.thencat.org/R2R/AcadPrac/CM/MathEmpFAQ.htm) course redesign as outlined by the National Center for Academic Transformation. In an emporium model class, students are required to spend a minimum number of hours each week in a laboratory setting, working with the online course materials, in this class primarily the study plan assignments. Teaching Assistants and/or instructors are present during these sessions to answer questions. There is usually at most one class meeting each week, during which the instructor focuses students' attention on upcoming tasks, presents study strategies, and perhaps gives an overview of previous or upcoming material. All students, regardless of condition, attended the same class meetings, had the same lab attendance requirements, and were taught by the same instructor. Study plan assignments and tests were identical for students in the control and experimental conditions. The only aspect of the class that differed between conditions was the composition of quiz questions. In both conditions, there were 12 quizzes, each containing questions covering learning objectives presented in the preceding week. There were two sets of objectives that were covered over a span of two weeks due to fall break and Thanksgiving. In the experimental condition, quizzes also contained questions covering objectives presented in earlier weeks.

Before students could access a quiz on MyMathLab®, they had to demonstrate adequate mastery of the learning objectives presented in the preceding week by scoring above 80% on a "quiz me" activity that was part of the quiz's corresponding study plan assignment. Critically, in the experimental condition, this requirement did not apply to objectives reappearing on a quiz due to the spacing manipulation. Consequently, students in the experimental condition received the same study plan assignments as students in the control condition. Students were required to take each quiz twice during a 48-hour window. Both quizzes covered the same set of objectives, and had the same number of questions. There were five exams throughout the semester and a cumulative final at the end of the semester. After each quiz and test, the data from MyMathLab® were de-identified before the analysis was conducted.

Results and Discussion

We analyzed performance on final exam questions assessing mastery of target objectives. For each student, we calculated the proportion of questions answered correctly. In the experimental condition, proportion correct was calculated separately for questions assessing mastery of spaced versus massed target objectives. In the control condition, in which all target objectives were massed, a single proportion correct score was calculated. In all analyses reported below, ACT Math score was used as a covariate. Estimated marginal means are reported.

Within-Subjects Analysis

We first examined the effect of spacing within-subjects by comparing proportion correct on spaced versus massed objectives within the experimental condition. Proportions correct for the two objective types were submitted to a repeated-measures ANCOVA. Although proportion correct on spaced objectives ($M = .71$) was, on average, higher than on massed objectives ($M = .67$), the difference was not significant, $F\ (1, 41) = 0.602$, $p = .442$.

Between-Subjects Analyses

We next examined the effect of spacing between-subjects by comparing proportion correct on spaced objectives in the experimental condition to massed objectives in the control condition. Proportions correct were submitted to a between-subjects ANCOVA. Students whose objectives were spaced had significantly higher scores ($M = .71$) than students whose objectives were massed ($M = .62$), $F(1, 91) = 8.49$, $p = .004$, $\eta_p^2 = .09$.

We also compared proportion correct on massed objectives within the experimental condition to proportion correct in the control condition, in which all objectives were massed. We submitted proportions correct to a between-subjects ANCOVA, as above. Proportion correct in the experimental condition ($M = .67$) was higher than in the control condition ($M = .62$) and this difference trended toward significance, $F\ (1, 91) = 2.48$, $p = .119$.

We conducted two additional between-subjects analyses to further illustrate the value of spacing. First, we calculated mean proportion correct across both spaced and massed target objectives in the experimental condition ($M = .69$) and compared that to proportion correct on target objectives in the control condition ($M = .62$) in a between-subjects ANCOVA. Proportion correct in the experimental condition was significantly higher, $F\ (1, 91) = 5.29$, $p = .024$, $\eta_p^2 = .05$. Second, we calculated overall proportion correct on the final exam for each student, including both target and nontarget objectives. Students in the spacing condition ($M = .65$) scored significantly higher than students in the control condition ($M = .58$), $F(1, 91) = 5.03$, $p = .027$, $\eta_p^2 = .05$.

Research suggests that an effective technique for enhancing long-term retention is retrieval practice[8, 9], especially when there are intervals of time between the retrieval attempts[10, 20]. In the current experiment, incorporating spaced retrieval practice over the course of a semester significantly increased students’ retention of the manipulated objectives. The difference in retention of spaced versus massed objectives cannot readily be attributed to differences between subjects in the experimental and control conditions. All students were taught in the same class by the same professor, obviating the possibility of instructor bias. Furthermore, students in the two conditions were matched on demographic characteristics, prior academic performance, and ACT Math scores.

There was some indication in this study that retention of massed objectives benefited from spacing retrieval practice of other objectives. While there was no difference in the retention of spaced objectives and massed objectives in the experimental condition (p = .442), the difference between the retention of the massed objectives in the experimental condition and the massed objectives in the control condition approached significance (p = .119). Within the experimental condition, spacing retrieval of some objectives may have increased mastery of massed objectives, rendering performance on the two objective types statistically indistinguishable, and leading to somewhat higher performance on massed objectives in the experimental condition than the control condition. If there were no "spill-over" effect of spacing on mastery of massed objectives, we would have observed equivalent retention of massed objectives in both conditions and significantly greater retention of spaced than massed objectives in the experimental condition. Chan[24] found that retrieving information can sometimes benefit retention of related, but untested, information—an effect dubbed retrieval-induced facilitation. Chan's research did not concern spaced retrieval practice, as was implemented in the current study, but it nonetheless seems plausible that increasing retention of some elements of calculus could have increased mastery of other elements, given the strong interrelatedness of elements and the fact that the acquisition of new mathematical knowledge requires retention of existing knowledge.

To our knowledge, this is the first evidence that spaced retrieval practice increases retention of complex mathematical information in a real-world classroom. This is encouraging for STEM instructors, whose students routinely exhibit poor retention of previously learned information, making it difficult for them to succeed in more advanced courses. To test whether our spacing manipulation will benefit performance in a subsequent course, we plan to measure the exam performance of students in the current study when they are in their next engineering mathematics course, *Engineering Analysis I*. We predict that students who were in the experimental condition of the current study will outperform students who were in the control condition, due to the former entering *Engineering Analysis I* with greater retention of knowledge acquired in *Introductory Calculus for Engineers*.

The current findings strongly suggest that engineering mathematics education could benefit from implementation of spaced retrieval practice. Our experimental design suggests one particular way to implement spaced retrieval practice—through spacing of quiz questions—but other methods are easily conceivable and could be tailored to the needs of individual instructors. Developing a spacing plan would surely require forethought and care on the part of instructors, but it may ultimately prove to be a highly efficient technique.

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Table 1

Distribution of Quiz Questions Targeting a Single Objective

Condition		Quiz 1	Quiz 2	Quiz 3	Quiz 4
Experimental					
	Spaced	Question 1	Question 2	---	Question 3
	Massed	Questions 1, 2, 3	---	---	---
Control		Questions 1, 2, 3	---	---	---

Note. Quizzes were one week apart.

Table 2

Demographic and Academic Characteristics of Students

Condition	% Male	% White	Math ACT *M* (*SD)*	High School GPA *M* (*SD)*
Control	68.0	78.0	25.6 (1.1)	3.8. (0.7)
Experimental	65.9	77.3	25.6 (1.4)	3.8 (0.4)

Table 3

Examples Objectives

Objective Number	Objective
1.1	Using the Order of Operations to Simplify Numeric and Algebraic Expressions
2.1	Solving Quadratic Equations by Factoring and the Zero Product Property
3.1	Determining the Domain of a Function Given the Equation
4.1	Understanding the Definition of a Logarithmic Function
5.1	Sketching Graphs of the Form y=Asin(Bx-C)+D and y=Acos(Bx-C)+D
6.1	Given the graph of a function, find designated limits and state its value at specified points.