Course design to encourage spaced practice

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Abstract:

From athletics, school clubs, coursework, and jobs to hanging out with friends, endless scrolling, or binge watching, students have constant competition for their time. Each student must prioritize their tasks. How much time should be devoted to reading a course textbook or reviewing class notes? When is the best time to complete homework sets or study for an assessment? Literature shows that students learn best when they space their practice or study over time [1]. However, students are not always disciplined to follow this advice and often leave their work to the last minute, cramming in study in less beneficial ways. Are there ways to redesign courses to encourage spaced practice? To examine this question, engineering professors from two different institutions, The United States Military Academy (USMA) and Calvin University (Calvin), applied different approaches to homework and frequent quizzes to encourage spaced practice for improved retention. The course at USMA was an introductory construction management course taught in the *Department of Civil & Mechanical Engineering*. The course at Calvin was an upper-level hydraulic engineering course required for all students graduating with a concentration in civil and environmental engineering or energy, environmental, and sustainability engineering.

The USMA instructor assigned ungraded homework with solutions available for reference and unannounced quizzes of low-grade value. The Calvin instructor assigned graded weekly homework sets (10% of course grade) and daily low-stakes quizzes (5% of course grade). At the beginning of each class, both instructors asked students to self-report the number of minutes they spent preparing for that lecture through textbook reading, completing homework problems, and reviewing past lecture material. Student time reports show some spaced practice encouraged by frequent low-stakes activities such as unannounced quizzes and regular homework submissions with peaks near high-stakes activities such as tests and lab reports.

Introduction

Dunlosky et al. (2013) evaluated ten techniques demonstrated to improve efforts on student learning. Of those, practice testing and spaced practice rated as "high utility" indicating that positive evidence has been consistently found [2].

Practice testing (retrieval practice) is a low-stakes or no-stakes practice or learning activity that requires the learner to retrieve previously learned information. It can be student or instructor led and is separate from summative assessments administered by the instructor [1], [3]. Benefits from practice testing are well established and retrieving information from memory during practice improves long-term retention more than restudying information [4]. In 2008, Karpicke and Roediger found that after initial learning on foreign language vocabulary and testing a week later, performance was substantially greater after continued testing (80%) than after continued study (36%) [5]. Many experiments involve learning vocabulary, but practice testing benefits expand to complex subjects such as math as well [4], [6], [7]. However, few studies explicitly

involve engineering courses. Practice testing can help students in two ways. First, taking a practice test can boost students' learning of the tested information which may enhance performance on subsequent exams. Second, they can help students figure out what they really know versus what they only think they know [2], [8]. Once students have demonstrated retrieval success on a concept, they can drop it from that study session to focus on more pressing ideas. However, they should include it in subsequent practices for continued long-term storage [2], [5]. Implementation of practice testing is broad, but several recommendations to maximize the potential of practice tests include:

1) Test frequently as more testing is better, but even one testing event is beneficial [3].
2) Include only the most important concepts, ideas, and content [2].
3) Provide a delay between instruction and testing [1], [3].
4) Use free recall or short-response formats, when possible, to require reconstruction from long-term memory, though a mixture of training types is also beneficial [2], [3].
5) Provide feedback, delayed when possible (for example, if the practice was given at the beginning of class, provide feedback in the middle as a break or at the end of class) [2].

Spaced or distributed practice refers to a schedule of practice that spreads out study activities over time instead of cramming (massed practice) shortly before an assessment [2]. Spaced practice also leads to enhanced retention and is more effective than massed learning [1], [4]. Instructors can space practice within a class by asking students to summarize key ideas from a lecture at the end of each class. They can space practice across classes by providing a review of those concepts at the beginning of the next class. As with practice testing, a longer interval between classes will likely improve long-term retention [2].

While each technique, practice testing and spaced practice, is an effective learning strategy on their own, research suggests they can be combined during implementation for increased benefit [4]. This can be accomplished by repeating some of the practice test questions across classes, a concept called "spaced retrieval practice" [2], [3]. Once a student understands material well enough to retrieve it from memory, additional retrieval practice increases the likelihood of long-term retention more than restudy and lengthening the time between practice increases the impact of those practices [4].

Despite evidence for improved long-term memory gain from spaced practice and practice testing, these practices are not often incorporated into the college setting and students do not necessarily engage in them unless the situation forces them to do so [1], [4]. It is not clear what causes this student tendency. However, classroom studies show that students retain more course content and earn higher grades when instructors implement assignments or activities that require students to practice retrieval more than they would on their own [6]. For courses like math and engineering, students must not only increase retention within a given course but across semesters [4].

Numerous studies have examined the impact of quizzing on motivation and performance [9], [10], [11], [12], [13], [14], [15]. In addition to impacting learning outcomes, spaced practice and practice testing may also influence the amount, frequency, and timing of out-of-class studying (i.e., lesson preparatory work). Online quizzes with respect to assigned readings have been

reported to increase student preparatory work to varying degrees [16], [17], [18], [19]. In-class quizzes, whether announced or unannounced, have also been reported to increase student class preparation [9], [11], [20], [21], [22]. Within various engineering disciplines various researchers have studied the spaced practice and preparation testing relationship with preparation [17], [18], but emphasis within the body of civil engineering literature is noticeably less [23]. This paper will attempt to address this gap.

Practice testing in the form of frequent classroom low-stakes quizzes is a way to modify the course schedule and class time to require spaced practice. Ideally students would engage (study) with material in anticipation for a quiz/practice, but at a minimum, they benefit from the practice testing during class. Frequent assessments (instead of midterms and finals) also space practice and require drawing on long-term memory. Homework is a form of practice, and the timing of homework sets and quizzes could encourage students to space their practice. Both techniques, practice testing and spaced practice, work toward the same goal of spacing practice for increased long-term retention. Two instructors at two institutions modified course schedules and activities to encourage spaced practice within civil engineering courses. Student-reported time spent outside of class was recorded for evaluation of study spacing. The course at USMA was an introductory construction management course taught in the *Department of Civil & Mechanical Engineering*; hereafter referred to as Course 1. The course at Calvin University was an upper-level hydraulic engineering course required for all students graduating with a concentration in civil and environmental engineering or energy, environmental, and sustainability engineering, hereafter referred to as Course 2.

Methodology

Schedule and course practice changes were implemented at both institutions during the fall 2024 semester to encourage spaced practice and evaluated for success. For each course time sheets and student pre- and post-semester surveys were collected to evaluate the success of practices.

Time sheets

Each meeting session, students recorded the estimated number of minutes they spent in preparation for class on time sheets passed around the classroom. Students were encouraged to record the amount of their individual out-of-class study time between the prior and current lesson in minutes. This included time spent reading the course textbook, reviewing previous lecture notes, completing homework problems, working on labs or other assignments, and studying for quizzes and tests.

For Course 1 a student in each class section was assigned the responsibility to manually distribute and collect an anonymous time survey sheet during the beginning of each lesson[1]. An example time survey sheet is available in Appendix A. For Course 2, time sheets were not passed around on test days or other days with unusual schedules; therefore, students only reported time for 28 lecture days. Additionally, students did not report time when they were absent from class.

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[1] On lessons in which high-stake exams are administered, time survey data is annotated directly on a student's exam by the student.

In these cases, the time entered on the following meeting day was used in analysis leaving a few gaps in collected data. Students who dropped the course before final grades were assigned were removed from analysis.

As the semester progressed, data from individual class time sheets was aggregated and subsequently formatted to produce a course-wide graph of study time. The course-wide graph includes labels for various course assignments and events (e.g., reports, presentations, quizzes, exams).

Student surveys

Student perceptions of the practices were assessed through surveys. Course 1 used a post-semester survey while Course 2 used both pre- and post-semester surveys.

Course 1's post-semester survey asked two questions related to unannounced quizzes. Both used a five-point Likert Scale format (Strongly Agree – 5 points, Agree – 4 points, Neutral – 3 points, Disagree – 2 points, Strongly Disagree – 1 point). Although individual student responses were anonymous, the survey was administered to two distinct student groups within each class section – one to civil engineering students and one to non-civil engineering students. The two "separate" surveys were identical in content and format and were provided simultaneously to each class section. In brief, the survey inquired 1) whether the student agreed or disagreed that unannounced quizzes increased class preparation time, and 2) whether the student preferred fewer unannounced quizzes to more announced (i.e., scheduled) quizzes.

After a short description of the types of practice, the pre-semester survey for Course 2 asked students how well they expected that practice to aid in their success on unit tests, final exam, and long-term retention past this course. They were also asked questions about the amount of time they expected to spend on various parts of the course and how they anticipated their study, or behavior would change with different schedules or grade arrangements. After the semester, students in Course 2 were asked how well they thought the practices helped them prepare for tests, final exam, and long-term retention as well as a few open-ended questions. For each question, students responded to the questions using a five-point scale where five represented high expectations or help in preparation and one represented low expectation or help. Specific survey questions are included for each course in Appendix B.

Course 1: Construction Management (United States Military Academy)

Construction Management is a three-semester-hour construction management course taught in the *Department of Civil & Mechanical Engineering* at *United States Military Academy*. The course is mandatory for all civil engineering students. Non-civil engineering students, however, that have selected the three-course infrastructure engineering sequence option also take the course. For this reason, non-civil engineering students, which may include students from any academic discipline at the institution, generally comprise most students enrolled in the construction management course any given semester. The course applies basic project management techniques to construction projects.

Administratively, the course has four to six class sections each fall semester and six to eight class sections each spring. The course is not offered during summer terms. Like most colleges and universities, multiple instructors are assigned to teach multi-section courses. Unlike most other schools, the Civil Engineering program at this institution assigns a senior instructor for each course. Part of the senior instructor's duty, besides teaching one or more of the course sections, is to ensure that each instructor prepares students across different sections in accordance with established course-wide administrative guidance, required textbooks, material and equipment, and lesson schedules, content, and objectives. To that extent, students in any one section could attend class with any other section at any point during the semester and not be ahead or behind the planned instruction. Consequently, assignments to include in-class quizzes and exams, are standardized (i.e., similar in format, content, and difficulty) to provide a fair, balanced, and transparent evaluation process.

The construction management course is segmented into three units of instruction comprising a total of thirty 75-minute lessons. Unit One: Construction Management Fundamentals encompasses fifteen lessons and is focused on project feasibility, programming and development, contractor selection, planning, execution, and project closeout. Units two and three comprise the remaining fifteen lessons and are primarily, but not exclusively, group work. To facilitate standardization and material coverage among sections and instructors, a course-wide student study guide is prepared and issued prior to each unit of instruction. For each lesson, the associated Unit Study Guide provides specific lesson objectives, reading assignments, key terms, a note-taking outline, and practice exercises with answers but not step-by-step solutions. In this paper the relationship between Course 1 practice testing (e.g., quizzing) and student class preparation will be examined with respect to Unit One.

Until recently (i.e., 2023 Fall semester), Course 1 used online reading pre-quizzes and four lengthy and moderately challenging homework assignments during Unit One instruction. The pre-quizzes were low-stake assessments (each worth 1% of the course grade); the homework assignments were high-stake evaluations (each between 5-9 % of the course grade). Scores on both pre-quizzes and homework assignments were generally high (between 88-92%). Subsequent performances on the mid-term and final exams were equally high. Anecdotally, the Course 1 co-author sensed that scores, whether individual or aggregate, were inflated based upon student interactions and observations within the classroom. Also noted were performance "loopholes" in the execution of pre-quizzes and homework problems. For the reading pre-quizzes, the desired outcome was a student who completed each lesson's preparatory studying and, as a result, formed a basic conceptual understanding of the assigned material and associated lesson objectives. Unfortunately, in the age of digital textbooks and ubiquitous search engines, unsupervised online quizzes are susceptible to "CTRL-F" and/or a few key words or phrases lifted from a particular quiz question. In those instances, the underlying conceptual objective is not only minimized but undermined and reduced to a simple task of searching and selecting the pattern matching choice. With respect to civil engineering homework assignments, the Course 1 co-author also observed student work that, while appropriately acknowledged, was often copied in part or in-whole from other students and or online student "tutorial" services or textbook solution manuals. In brief, while most students, especially high achievers, did complete online

quizzes and assigned homework problems individually and in earnest, there were enough awkward pauses during in-class lesson discussions to warrant concern about meeting student outcomes and lesson objectives. As such, the Course 1 co-author instituted a few course-wide changes.

During the 2024 Fall semester, four unannounced quizzes were administered to students at the beginning of a class period. The quizzes were graded, but each was a low-stakes evaluation (i.e., an individual quiz was worth approximately 2% of the overall course grade). The level of difficulty for the quizzes was low. The quiz questions were intended to test what students know (i.e., can recall) and were not designed to test a student's ability to apply principles and concepts to complex problems. Each quiz was comprised of questions generated from the preceding lesson's material and related to published lesson learning objectives. Questions took various formats: multiple choice, true and false, fill-in the blank, or short answer. Each quiz had two to four questions. No quiz was designed to last longer than six minutes and most students finished with ample time to spare. Two of the four quizzes had an optional bonus question of similar difficulty and scoring potential as the non-bonus questions.

To put these changes and others in perspective, the Spring 2023 semester Unit One consisted of twelve lessons with ten reading pre-quizzes, four homework problem sets, and one exam. By the Fall 2024 semester, Unit One consisted of fifteen lessons with four unannounced quizzes and two scheduled exams, one at lesson seven and one at lesson fifteen.

Course 1 Results and Analysis

Figure 1 shows the Course 1 Student Time Survey results for the 2023 Spring semester. Unit One consisted of twelve lessons and fifteen graded events. During this unit of instruction, nine low-stakes reading pre-quizzes (10 points each or 0.5% of the course grade) were administered online via Microsoft Teams. It is important to note that the course considers only low-stakes and high-stakes categories with respect to assignment classification. A low-stake assignment is worth less than 2.5% of total course points. A high-stake assignment is worth 2.5% or greater of total course points. Four homework assignments (high-stakes and each averaging 4.125% of the course grade) were assigned and due at Lessons 4, 6, 9, and 11, respectively. On average, students spent approximately 85 minutes on each homework assignment which heavily influenced the daily average study time of 59 minutes leading up to the first exam. Consistent with prior semesters, technical content covered during Lessons 7 through 10 reflected noticeably lower student study times. Reading quizzes took on average less than 10 minutes per student. Any remaining studying or preparation time per lesson is anecdotally attributed to students working primarily on homework assignments prior to the night before they were due. The Unit One exam was a high-stakes event (250 points or 12.5% of the course grade). The course-wide exam average was 91.0%. One assignment, a reflection essay based upon a construction site visit, was not collected until the next unit of instruction. In other words, students did not need to complete the essay before the exam so its impact upon student study time during Unit One is assumed to be negligible.
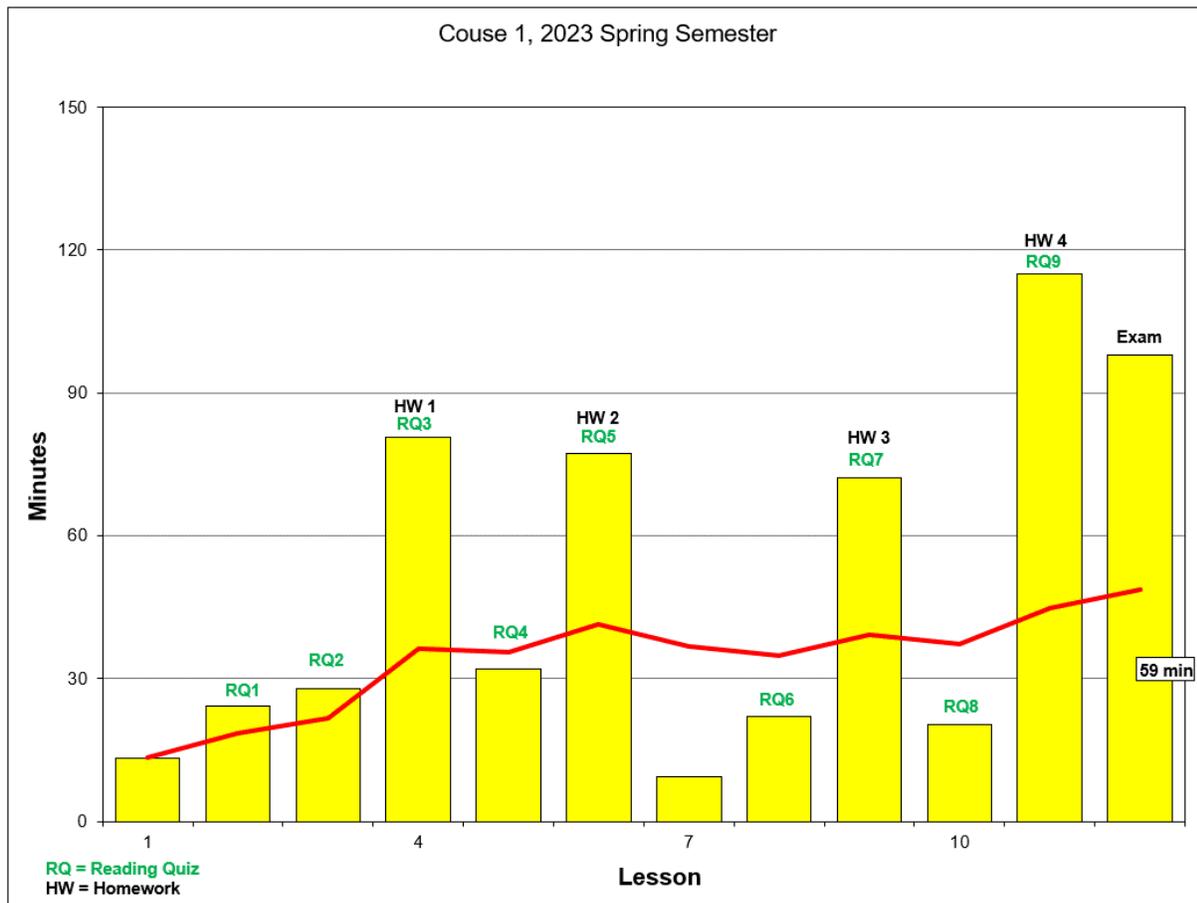
Figure 1. Course 1 Student Time Survey by Lesson, 2023 Spring Semester

Figure 2 shows Course 1 Student Time Survey results for the 2023 Fall semester. Unit One consisted of twelve lessons and eight graded events (three low-stakes, five high-stakes). Low-stake reading pre-quizzes were removed from Unit One. Four high-stakes homework assignments, each averaging 4.125% of the course grade, were assigned with due dates at Lessons 4, 6, 9, and 11. On average, students spent approximately 123 minutes on each homework assignment which heavily influenced the daily average study time of 65 minutes leading up to the first exam. Consistent with prior semesters, technical content covered during Lessons 7 through 10 reflected noticeably lower student study times. Reading quizzes were replaced by three low-stakes unannounced quizzes valued at 20 points each or 1.0% of the total course grade. The Unit One exam was a high-stakes event (250 points or 12.5% of the course grade) and the course-wide exam average was 88.0%, which was approximately 3% lower than the previous semester's average. There were two substantive percentage point changes to the exam: 1) the Multiple-Choice question section went from 10% to 14% of the exam, and 2) the Estimating Scenario portion went from 18% to 14%, respectively.
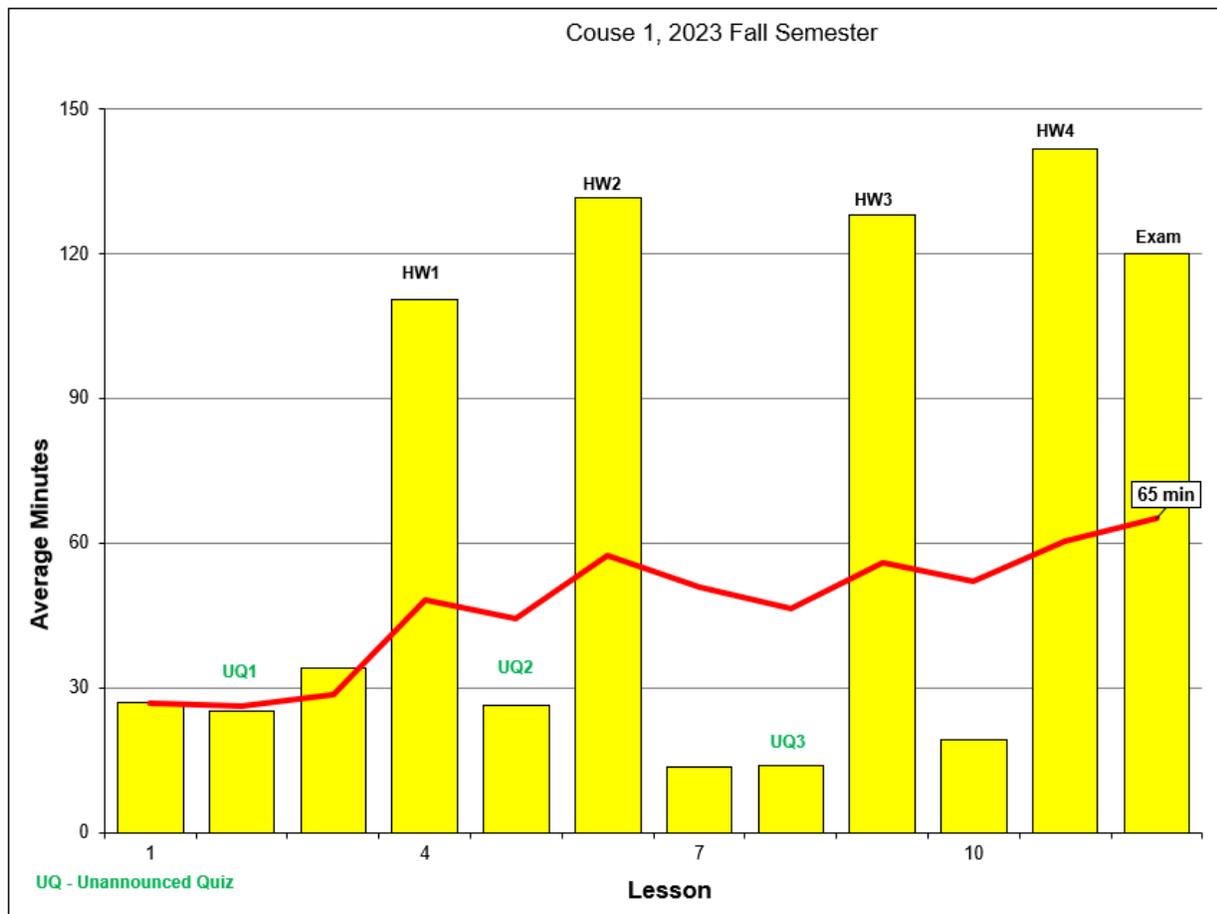
Figure 2. Course 1 Student Time Survey by Lesson, 2023 Fall Semester

Figure 3 shows Course 1 Student Time Survey results for the 2024 Spring semester. Unit One increased by two 75-minute lessons to fourteen total lessons. There were six graded events during Unit One: a decrease of two from the previous semester. Homework assignments one through four from the previous semester were removed from the course. Reading quizzes were replaced by three announced quizzes at Lessons 4, 7, and 11. Each announced quiz, a high-stakes event, was valued at 50 points or 2.5% of the total course grade. In addition to the three announced quizzes, two unannounced quizzes were administered at Lessons 2 and 13. Each unannounced quiz, a low-stakes event, was valued at 20 points or 1.0% of the total course points. Of note, the removal of the four homework assignments heavily influenced the decrease in average daily study time to 35 minutes. Consistent with prior semesters, technical content covered during Lessons 8 through 12 reflected noticeably lower student study times. The Unit One exam was a high-stakes event (250 points or 12.5% of the course grade). No changes were made to the 2024 Spring Semester exam compared to the 2023 Fall Semester exam. Even though the high-stakes homework assignments were removed from Unit One, the course-wide exam average increased 0.6% to 88.6% from the previous semester.
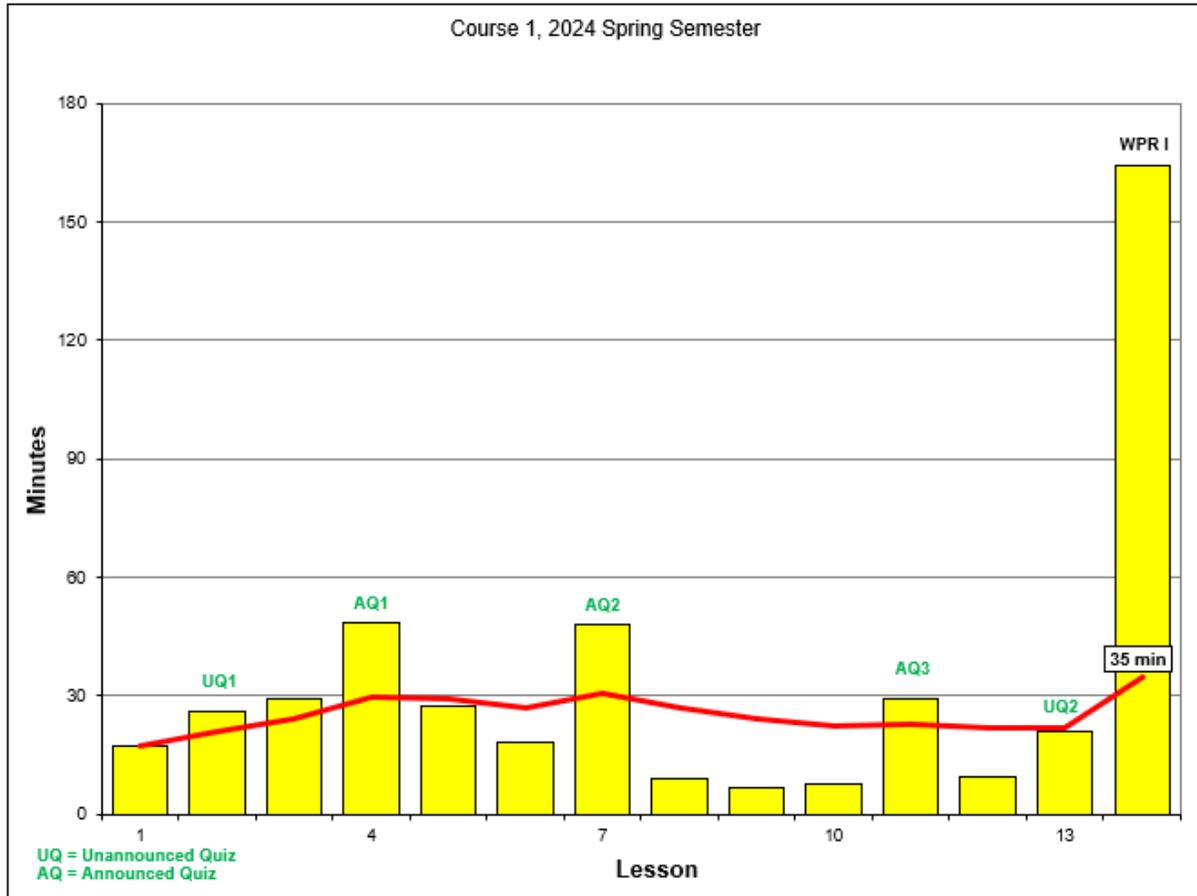
Figure 3. Course 1 Student Time Survey by Lesson, 2024 Spring Semester

Figure 4 shows Course 1 Student Time Survey results for the 2024 Fall semester. Unit One consists of fifteen lessons: an increase of one from the prior semester. The additional lesson was necessary to add an exam within the Unit One block of instruction. Although the number of graded events remained at six from the prior semester, the number of high-stake events decreased from four to two while the number of low-stake events increased from two to four. The four unannounced quizzes, each worth 40 points or 2.0% of the course grade, were administered at Lessons 2, 4, 12, and 14. The two exams, each worth 250 points or 12.5% of the course grade, were administered at Lessons 7 and 15. Both exams were cumulative, but Exam 2 concentrated on material covered during Lessons 8 through 14. On average, students spent 30 minutes preparing for each lesson, a decrease of 5 minutes per lesson from the previous semester even when accounting for the additional exam. Consistent with prior semesters, technical content covered during Lessons 8 through 13 reflected noticeably lower student study times. The average scores for Quiz 1 through 4 were 76.6%, 80.4%, 78.3%, and 77.4%, respectively. The weighted average of all four quizzes was 78.25%. However, with respect to the two exams, students studied an average of 93 minutes for Exam 1 and 167 minutes for Exam 2. The course-wide averages for Exam 1 and Exam 2 were 83.1% and 88.5%, respectively. Thus, the average for the two exams was 85.8% (i.e., a "B"). This is nearly 3% lower than the single exam (88.6% or

"B+") administered during the 2024 Spring Semester which covered the same material, albeit in less depth, breadth, and contextual emphasis.
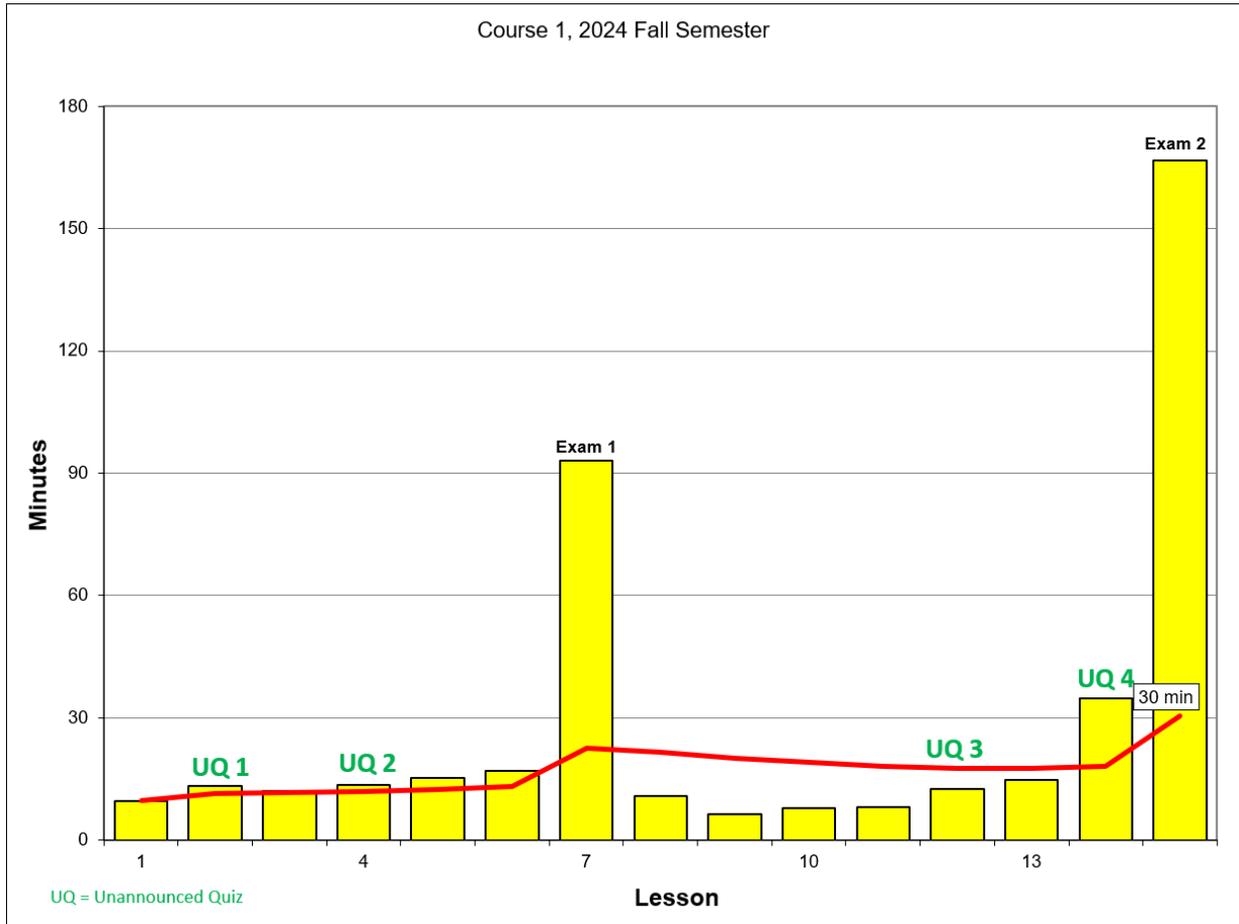

Figure 4. Course 1 Student Time Survey by Lesson, 2024 Fall Semester

Course 1 conducted a post-course student survey. Two questions relevant to this paper were asked in separate but identical surveys to civil engineering and non-civil engineering students (Table 1). Student responses were anonymous. Table 1 shows question 1 and 2 survey results for Course 1 civil engineering students. Table 2 shows question 1 and 2 survey results for Course 1 non-civil engineering students. Table 3 shows question 1 and 2 survey results for all Course 1 students.

Table 1. Course 1 End-of-Course Survey Questions

Question #	Question
1	Unannounced quizzes increased the amount of time I spent preparing for each class than I would have if there were no such quizzes.
2	I prefer fewer unannounced quizzes to announced daily quizzes.

Table 2. Course 1 Survey Results – Civil Engineering Students

Question 1	# Resp	15	%	Question 2	# Resp	15	%
	Strongly Agree (5 pts)	3	20.0%		Strongly Agree (5 pts)	4	26.7%
	Agree (4 pts)	7	46.7%		Agree (4 pts)	7	46.7%
	Neutral (3 pts)	1	6.7%		Neutral (3 pts)	2	13.3%
	Disagree (2 pts)	3	20.0%		Disagree (2 pts)	1	6.7%
	Strongly Disagree (1 pt)	1	6.7%		Strongly Disagree (1 pt)	1	6.7%

As evidenced from Q1, 66.7% of civil engineering students, or 2 out of 3, agreed that unannounced quizzes increased the amount of time they spent preparing for class. Less than 1 student out of 3, or 26.7%, responded to the contrary. Although the average time spent was low, it was higher than the average time spent completing the online reading quizzes from the 2023 Spring semester. Furthermore, nearly 3 of 4 civil engineering students prefer fewer unannounced to more announced quizzes.

Table 3. Course 1 Survey Results – Non-Civil Engineering Students

Question 1	# Resp	61	%	Question 2	# Resp	61	%
	Strongly Agree (5 pts)	12	19.7%		Strongly Agree (5 pts)	24	39.3%
	Agree (4 pts)	17	27.9%		Agree (4 pts)	7	11.5%
	Neutral (3 pts)	12	19.7%		Neutral (3 pts)	14	23.0%
	Disagree (2 pts)	16	26.2%		Disagree (2 pts)	12	19.7%
	Strongly Disagree (1 pt)	4	6.6%		Strongly Disagree (1 pt)	4	6.6%

As evidenced from Q1, 47.6% of non-civil engineering students, or nearly 1 out of 2, agreed that unannounced quizzes increased the amount of time they spent preparing for class. Less than 1 student out of 3, or 32.8%, responded to the contrary. Although the average time spent was low, it was higher than the average time spent completing the online reading quizzes from the 2023 Spring semester. Furthermore, a simple majority of non-civil engineering students, or 50.8%,

prefer fewer unannounced to more announced quizzes. One in four non-civil engineering students, or 26.3%, do not prefer fewer unannounced quizzes to more announced quizzes.

Table 4. Course 1 Survey Results – All Students

	# Resp	76	%		# Resp	76	%
	Strongly Agree (5 pts)	15	19.7%		Strongly Agree (5 pts)	28	36.8%
	Agree (4 pts)	24	31.6%		Agree (4 pts)	14	18.4%
Question 1	Neutral (3 pts)	13	17.1%	Question 2	Neutral (3 pts)	16	21.1%
	Disagree (2 pts)	19	25.0%		Disagree (2 pts)	13	17.1%
	Strongly Disagree (1 pt)	5	6.6%		Strongly Disagree (1 pt)	5	6.6%

As evidenced from Q1, 51.3% of all students, or 1 out of 2, agreed that unannounced quizzes increased the amount of time they spent preparing for class. Less than 1 student out of 3, or 31.6%, responded to the contrary. Although the average time spent was low, it was higher than the average time spent completing the online reading quizzes from the 2023 Spring semester. Furthermore, a majority of all students, or 54.8%, prefer fewer unannounced to more announced quizzes. Less than 24% prefer more announced quizzes to fewer unannounced quizzes.

Course 1 Discussion

Course 1 student time surveys show an absolute decline from the 2024 Fall Semester when compared to prior semesters. However, this decline in average study time per student must be placed in context. As explained in the Methodology section for Course 1, structural and programmed differences between the two semesters exist. Structurally, Unit One of the 2024 Fall Semester had 15 lessons, the 2024 Spring Semester had 14 lessons, and both the 2023 Fall and Spring Semesters each had 12 lessons. Requirement wise, Unit One of the 2024 Fall Semester had 6 total assignments (4 low-stakes and 2 high-stakes). The 2024 Spring Semester had 6 total assignments (2 low-stakes and 4 high-stakes). The 2023 Fall Semester had 8 total assignments (3 low-stakes and 5 high-stakes). Finally, the 2023 Spring Semester had 12 total assignments (9 low-stakes and 5 high-stakes).

Course 1 Unit One grade performance, while not a direct objective of course-wide changes, does reflect a relative decline in average exam scores. Here again, context is important. The 2023 Spring and Fall Semesters had one 75-minute exam, as did the 2024 Spring Semester. The 2024 Fall Semester had two 75-minute exams. While the two 2024 Fall Semester exams covered the same material that previous Unit One exams covered, the 2024 exams contained more total questions. In short, the 2024 exams, especially Exam 1, were intentionally more rigorous and in-depth. This alone could account for the lower overall scores. When performance was looked at in

detail, however, the grade distribution from 2023 to 2024 flattened out (i.e., the middle portion of the grade distribution curve moderately extended, but the number of high performing students per capita remained consistent). Furthermore, average final course grades from 2023 to 2024 showed a noticeable but unremarkable 2% approximate decline (91% to 89%, or A- to B+). This decline is likely due to the increase in testing rigor.

Anecdotally, and related to classroom observations reported earlier, 2024 Fall grades are not considered to be as inflated as 2023 Spring semester grades. Although exam scores and final grades were lower, noticeable to the Course 1 co-author was an appreciable and positive difference in the amount, type, and quality of student questions and student generated discussions that occurred during 2024 Fall semester lessons as compared to previous semesters. The co-author attributes this positive development to the emphasis on contextual understanding. This is not unique to this co-author, as other researchers have reported similar observations [19], [21]. When viewed from both qualitative and quantitative perspectives, results associated with the changes the author instituted are mixed. Average student study time during Unit One lessons did not appreciably increase. Student study time associated with lessons having technical material remained consistently lower than lessons emphasizing non-technical material. Finally, exam and course grades decreased. This decrease, however, is likely attributed to an increase in exam difficulty as opposed to the variation in the number of graded events.

The incremental changes during the Unit One course of instruction over time does, however, reveal a potential "best" strategy related to the number and type of graded events. The 2024 Spring Semester, having 3 "lower" high-stakes events in the form of announced quizzes along with 2 low-stakes unannounced quizzes and one high-stakes exam, seems to be near the "sweet spot" balancing event number and type with performance. Comparatively to the 2024 Fall Semester, the 5-minute increase in daily study time, while small in absolute numbers, does represent a 16.7% increase. It is noteworthy that fewer unannounced quizzes and more announced quizzes also align with the results of the student survey provided earlier.

Course 2: Hydraulic Engineering (Calvin University)

Course 2 is a four semester-hour hydraulic engineering course that applies basic principles of fluid mechanics to practical problems in hydraulic and hydrologic analysis. It is a required course for junior civil and environmental engineering students, senior energy, environment, and sustainability engineering students, and an elective for all engineering students. The course meets in-person three days a week for 65 minutes each session. It has a lab component that meets outside of regularly scheduled lectures. Students attending Calvin University are typically well-prepared for college-level work and involved in several extracurricular activities. Many students also work part-time. Most engineering freshmen are calculus ready but have access to educational support as needed. Calvin University is a private, liberal arts institution with competitive sports, rigorous academic expectations, and an active student-life. For the past few years, spaced practice has been encouraged in *Hydraulic Engineering* by providing frequent quizzes, weekly homework, frequent tests and a final exam. While student feedback was provided each year for continual course development, the time students spent outside of class preparing for sessions was not considered or measured. These practices were revised Fall 2024 to

encourage and track spaced practice for improved long-term learning. Practices included weekly graded homework sets, daily low-stakes quizzes, and frequent high-stakes tests.

Almost every week, students had homework sets to complete that were due the following week. These ranged from 6-10 problems and required students to document the steps and process to solve them. Students were graded on the documentation as well as correct answers. Once students uploaded their homework online, solutions were available for study and review. Interleaving is a practice where students practice already-learned concepts along with to-be-learned concepts and is demonstrated to improve long-term retention as well [8]. Each homework set included several interleaved problems covering material from previous sets. Along with most homework sets, students had modeling problems that they completed in small groups. These helped students apply course material to real-life problems like stream restoration of a local creek or rural water delivery over a mountain.

Quizzes and tests were spaced frequently throughout the semester. One to two days a week, class began with a low-stakes, short, graded quiz. These 1-6 question quizzes ranged from 2-9 points and covered material from textbook reading, recent lectures, homework, and a few from previously covered material. Therefore, quizzes served as practice testing at regular spacing for to-be-learned material and expanding spacing for already-learned material [3]. The questions were printed on paper for students to complete. After a few minutes, solutions were projected while students switched writing tools and self-graded their quizzes. Quizzes usually included short answer or quick calculation questions with occasional longer problems more representative of a homework or test question. Four unit tests were spaced throughout the semester. Tests included longer problems often combining several smaller concepts to demonstrate mastery of the learning outcomes. The final exam was cumulative and included a few questions directly from the daily quizzes along with several problems like the unit tests. It focused on key learning outcomes and frequently missed outcomes.

Graded course components can be sorted into low-stakes and high-stakes activities as seen in Table 5. Low-stakes activities for Course 2 include daily quizzes, weekly homework, and demonstrations. These assignments are designed to encourage spaced practice. High-stakes activities include a research presentation, lab reports, tests, and the final exam.

Table 5. Low-and high-stakes graded activities with low-stakes shaded in grey.

Graded Activity	Grade contribution per event (%)	Grade contribution to final course grade (%)
Daily quizzes	0.3	5
Weekly homework	1	10
Modeling problems	~1.6	8
Research presentation	5	5
Lab Reports	4-8	12
Tests	10	40
Final Exam	20	20

Course 2 Results and Analysis

Reported time

In the pre- and post-semester surveys, students were asked to estimate the amount of time they would (or did) spend reading the textbook, reviewing lecture notes, working on homework problems, and in other ways in preparation for each 65-minute lecture. Time predictions and estimates are included in Table 6. The average time spent per lecture as reported on the time sheets ranged from 51 to 161 minutes per student with a class average and median of 112 minutes. The time estimates reported on the pre- and post-semester surveys are greater than what was reported on time sheets. One would think that the time sheets would be more accurate because students only need to recall time spent in the previous few days. However, on the post-semester survey, one student commented, "I don't think the data for how long we spent in preparation for class each week (on the paper we passed around) will be very accurate. At least for myself, it's hard to estimate how long something takes, especially if it's not all done in one sitting (student 1)." This student perspective is something to consider for analysis.

Table 6. Student estimated and reported time spent in preparation for lecture session

	Pre-semester time predicted (N=28)	Post-semester time estimated (N=17)	Average of estimated time for each lecture collected during the semester
Reading	29	9	
Reviewing notes	17	11	
Homework	98	107	
Other	20	5	
Total	**164**	**132**	**112**

Figure 5 shows the course-wide aggregated data of estimated time spent in preparation for each lecture along with the running average. Labels for various events (homework, tests, labs, brief) are displayed on this plot and explain the time peaks during the semester. Because time estimates were not passed around consistently, there are some gaps, however some observations can be made regarding student behavior.

Little time was invested in the course at the beginning of the semester between lecture days 2 and 6. No assignments were due and there was a holiday. It seems that students had little motivation to prepare for class.

Practice was relatively spaced out for the low-stakes assignments as indicated on lecture days 7, 10, 13, 16, 19, 22, 25, 28, 31, and 38 when homework sets were due. Students reported an average of 90 minutes of time spent outside of class when only homework sets were due (as opposed to when both homework and a test occurred).

More time was spent near tests, a high-stakes event. Most notably, time reported on days following tests (14, 20, and 30) is significantly higher than other days. Because time sheets were not collected on test days reported time included time spent completing a homework set and test

preparation. The average reported time on lectures 14 and 20 was 235 minutes. Based on average homework time, this indicates students spent approximately 145 minutes preparing for the test. Several events occurred within a short period and time spent on all of them were reported on lecture 30. Time sheets were not collected on lecture days 28 and 29 either so the high time (801 minutes) reported on lecture 30 likely includes time spent over several days on homework, a test, and a large lab. However, even if students split this time evenly among days 28-30, it still would have far exceeded other lesson preparation times. Or consider previous analysis of an average of 235 minutes spent on homework and test preparation, students spent 566 minutes outside of class during this week. The lab report might explain this additional time. Students had two weeks to collect the lab data and write the report between lecture days 24-30, but it appears they completed most of that work near day 30.
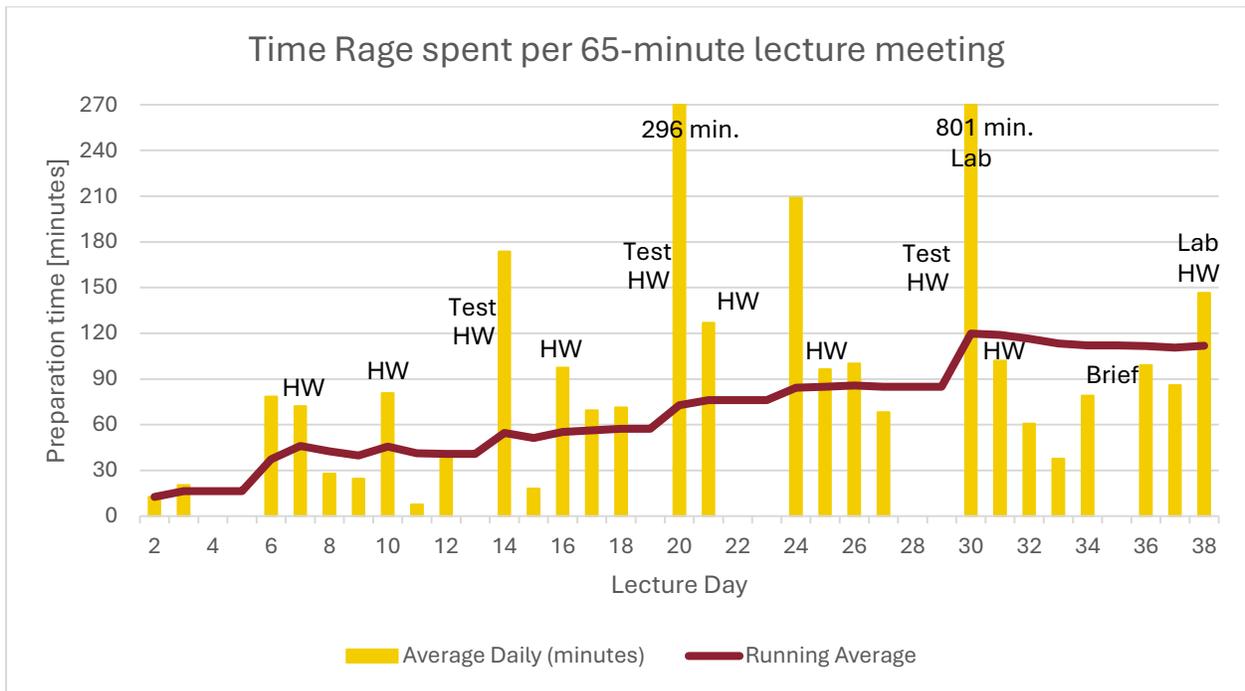

Figure 5. Course 2 aggregated time spent per 65-minutes lecture session with low-stake (HW) and high-stake (tests/lab/brief) activities noted. Vertical axis reduced for comparison to figures 1-4. Average daily minutes that exceeded the vertical axis are list.

Lecture days 34-38 provide additional insight into students' study spacing. On day 35, students had a group research presentation due (brief). They would present on days 35 and 36 with no new material presented that week. Instead, they were supposed to be writing a lab plan, conducting the lab, and then writing a report that was due shortly after day 38. Instead, it appears that they did not spend very much time on this class that week (34-36) and pushed that work off until the following week when it was due, just after lecture 38 (days 37-38).

Figure 6 displays the estimated time from all students over the semester for each lecture separated out by low-stakes and high-stakes activity days (N=846). On 163 occasions, students did not spend any time preparing for low-stakes class, but this is true on only 4 occasions for high-stakes activity days. While 163 days with no preparation seems high, 76% of lecture days,

students spent at least some time preparing for low-stakes classes. However, the high-stakes events demanded more time and students still tended to procrastinate until those were due. In the post-semester survey, students shared how teaching practices encouraged spaced practice. While not the focus of this paper, interleaving was included in homework assignments and proved helpful to one student. "I thought the review homework questions were a good way to have spaced out review (student 1)." Students provided reasons for not spacing their practice more including their own procrastination and competition for time with other classes.

> *The biggest thing that kept me from spacing out the review and practice in the course was myself. I would procrastinate the assignments to the last minute. (student 32)*

> *What kept me from spacing out my review was the fact that I usually had other classes to work on and felt that I could put off the review and still get a good grade. (student 4)*
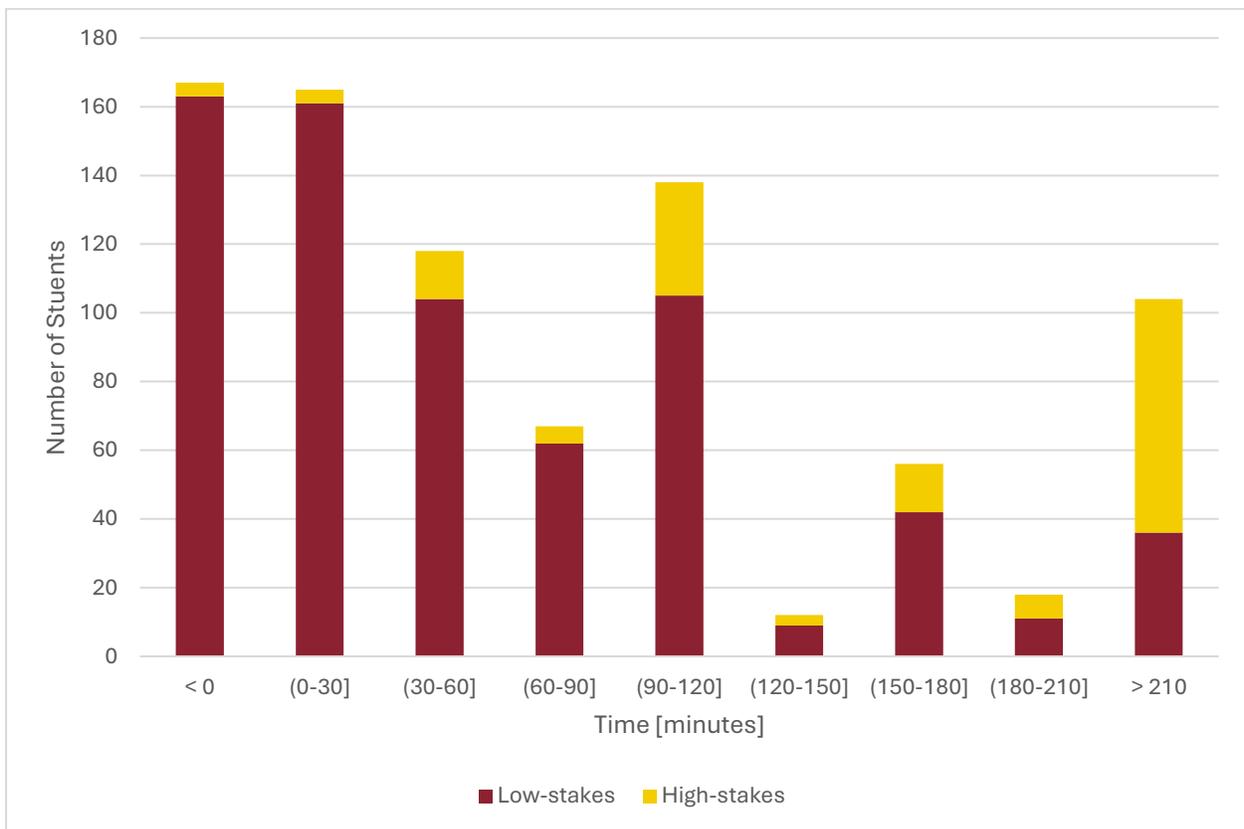

Figure 6. Distribution of reported time spent outside of class in preparation for 65-minute lecture separated by low-stakes (N=693) and high-stakes (N=152) activities occur.

Survey Perspectives on Practices

In the pre-semester survey, students were asked to rank how well they expected each course practice (spaced homework and frequent quizzes) to contribute to success on unit tests, the final exam, and long-term retention past the course and in the post-semester survey, they were asked how well these practices, as implemented, contributed to their learning. For both surveys, 5 is high and 1 is low. Student responses are summarized in Table 7. Pre- and post-survey responses

for spaced homework were the same except after completing the homework, students thought it would not help them with long-term retention as much as they did before the semester. On the post-semester survey, they ranked frequent quizzes much lower, likely showing a disconnect between frequent quiz content and tests.

Table 7. Pre- and post-semester survey question responses from Course 2.

Pre-semester questions	Average Score (from 1 to 5, with 5 being most familiar/highest expectations)	
	Spaced HW Practice	**Retrieval Practice**
How well do you think it **will help** you prepare for the unit tests?	4.2	4.0
How well do you think it **will help** you prepare for the final exam?	4.1	3.7
How well do you think it **will help** you remember concepts past this course?	4.0	3.9
Post-semester questions	**Average Score (from 1 to 5, with 5 being most familiar/highest expectations)**	
How well do you think it **helped** you prepare for the unit tests?	4.2	3.4
How well do you think it **helped** you prepare for the final exam?	4.1	3.2
How well do you think it **helped** you remember concepts past this course?	3.8	3.5

In the pre-semester survey, students were asked how their time estimates and practice expectations would change if the grade contributions differed. When asked how their responses would change if frequent quizzes were worth a total of 15% of their grade instead of only 5%, tripling in value, twelve students thought they would experience increased stress while twelve thought they would study and prepare more if the contribution to the final grade from the frequent quizzes increased. Tension exists around all assessments and daily quizzing is no different. Example student feedback explain their reasoning. (N=26 for quiz free response)

> [T]his would put more emphasis on preparing adequately for the quizzes. This would make me understand more things in a deeper way. (student 4)

> I think that would make me have to study a lot more and be more stressed for these versus the lower stakes ones would help me to just review my notes and still get a little grade boost but check my knowledge and how well I'm doing in the course. (student 28)

> *I feel like I would study more for each one, however be more stressed if I didn't have time to study or didn't perform well one week of the semester. (student 17)*

Students were asked how their time and effort would change if homework was not graded, making it even lower stakes. Seventeen students responded in ways that suggest ungraded homework is not conducive for spaced practice or learning. Ten thought ungraded homework would result in less time spent on homework, six reported less motivation to complete it, and seven expected less overall learning from ungraded homework (some students reported more than one expectation). However, three students thought ungraded homework would result in an increased focus on learning without the stress of a graded answer and seven students recognized the importance of completing homework assignments for the purpose of learning and did not expect grading to change any behaviors. Selected student quotes below explain their reasoning. (N=27 for HW response)

> *I believe that putting a grade on the assignments forces you to complete the assignments, creating a bit of accountability for completing the assignment. For me, it is something where once I understand the concept that is being taught, I tend to understand how to complete problems involving the concepts, however the graded homework forces me to apply the concepts and ensure that I can apply it properly. Taking away the grade would likely result in me not completing the assignments at all. (student 32)*

> *If weekly homework was not graded, I would be less concerned about getting the correct answers, which would admittedly make me learn less. I would see myself skipping out on my own learning. I would spend less time struggling with questions and spend that time elsewhere. (student 4)*

> *If the homework was not graded, I would spend time doing it well and doing the same exact things as if it were graded because it would serve me as practice for the test. (student 18)*

> *Having non-graded homework allows me to figure out the problem without the pressure of having to get it right all the time. It allows me to understand my mistakes without the anxiety of maintaining a good grade for the course. (student 21)*

Course 2 Discussion

While frequent quizzing improves long-term memory and recall, and reveals what students really know versus only think they know, daily quizzes as implemented in Course 2 did not encourage students to space their out-of-class practice [2], [4], [8]. There are several possible explanations for this. Some students felt that the daily quizzes did not reflect the test material. Additionally, the grade contribution from each daily quiz was quite low and the sum of all quiz grades was only 5%. This may not have been enough extrinsic motivation for students to change behavior. The low grade-weight of the daily quizzes was not enough to encourage spaced review, but students indicated increasing the grade-weight would also increase stress. Students were briefed on the benefits of frequent quizzing at the beginning of the semester, but those benefits must not have been of high enough value to change behavior either. Engineering students take multiple classes requiring homework, labs, and tests. These courses, along with extracurricular activities,

compete for time and attention, leading to procrastination where possible. Overall, students responded favorably to daily retrieval quizzes. "Although I usually don't need review, retrieval practice and interleaved homework are incredibly valuable to me. They help me keep track of how well I am retaining knowledge from the course, and they help hammer home key topics. This increases my retention, and my confidence on tests, making the entire course more enjoyable. Every professor should do this (student 29)."

The weekly homework sets in Course 2 may have helped students space practice. As seen in Figure 5, time was spent near homework due dates, but time spent prior to lectures 6, 17, 18, 24, 26, and 27 was similar. This suggests students spaced homework practice, completing several problems per day instead of all at once.

Tracking Course 2 students' time spent in preparation for lecture provides insight into their lives. An unexpected result of this is the ability to adjust the schedule for subsequent semesters to support their study or work-life balance. On average, students spent 112 minutes per lecture outside of class. It is typical to expect 2-3 hours of out-of-class study for every 1 hour in class, so this reported time is at the low end of the expectation. However, the high peaks reported could indicate places where the instructor could change assignment due dates to space out practice. For example, the average time reported on lecture 30 was 801 minutes. This included time spent preparing for three lectures, so it is unclear if students spaced out this time or crammed the day before. Likely, it was a bit of both. This time includes a homework set, test preparation, and a large lab report. Regardless of whether students spaced out these 801 minutes over three lectures or not, it demonstrates a lot of outside of class time. If the lab was due a few days later, it's possible this time could have been better spaced and may have supported the students' life-study balance better. The lab could have included some interim assignments or check-ins to require students to work on it over the few weeks leading up to the due date as well. Another high-time day was lecture 20 (296 minutes). Time sheets were not collected on lecture 19 so it's possible the 296 average minutes were split over two days, but even if that occurred, 148 minutes for one lecture is on the high end. The instructor could review assignments around lecture 19 to make sure they are valuable to require this amount of time or adjust the schedule accordingly.

With competing courses and activities along with their own tendency to procrastinate, Course 2 students admit they do not space out practice well. However, due to the timing of homework, some spacing was required and evident by student-reported time sheets. Students viewed weekly graded homework sets and daily low-stakes quizzes favorably with homework having the greatest contribution to success on unit tests (4.2 out of 5). Time sheets also demonstrated peaks near high-stakes events.

Conclusion

There are numerous ways to schedule low- and high-stakes activities throughout a semester and instructors of course 1 and 2 demonstrated the ability to encourage spaced practice through careful scheduling of frequent quizzes and homework.

Course 2 followed the "more testing is better" approach and kept quizzes low-stakes, but failed to only include the most important concepts and some students felt that the daily quizzes did not reflect the test material [2], [3]. As recommended by the literature, quizzing was delayed from instruction, quiz questions were a blend of free recall or short response with calculations, but feedback was provided immediately [1], [2], [3]. Despite this, the grade contribution of Course 2 frequent quizzes was not high enough to motivate students to space their study. Nor was the grade and learning benefits expected from frequent quizzing as reported by literature. Course 1 incrementally changed both the amount and type of testing from the 2023 Spring Semester through the 2024 Fall Semester (i.e., quantities and types of both low-stakes and high-stakes events). To that end, Course 1 dramatically reduced the number of graded events (e.g., from a high of 15 during the 2023 Spring Semester to a low of 6 during the 2024 Spring and Summer Semesters). Unsurprisingly, this reduced the amount of out-of-class daily study time recorded by students. The impact upon performance, however, was not clear cut. Quiz and exam performance, while lower, also coincided with the development and implementation of more rigorous testing. Based upon historical results, the decrease in scores is attributed more to increased level of difficulty as opposed to reductions in student study time (which was heavily influenced by high-stakes homework assignments).

The two courses described herein took different approaches to homework as well. It is important to recognize that Course 1 is a Construction Management course while Course 2 is considerably more technical as it applies fluid mechanics to hydraulic and hydrologic analysis. Course 1 eliminated high-stakes, high time requirement homework assignments that did not, from both exam performance and anecdotal evidence, provide commensurate value in terms of time, effort, and substance. While homework assignments in Course 1 may have helped students space practice, replacing those assignments with "lower" high-stakes announced quizzes and low-stakes unannounced quizzes arguably had the same spacing effect. Weekly homework in course 2 was a low-stake activity, at 1% each set, but students completed them with high expectations of their contribution to overall course success. Student reported time indicates weekly homework encouraged spaced out-of-class practice, however review of the time sheets suggests room for improvement. In Course 2, homework sets were due the day of the test on that material. A possible improvement would be to have them due the lecture before the test. This would further space out practice and allow time for students to ask questions prior to the test.

The findings from Course 1 support the findings from Course 2 that instructors can encourage spaced practice by carefully scheduling practice events. The incremental changes made to Course 1 over four consecutive semesters indicate a potential "sweet spot" with respect to the timing, number, type, and weighting associated with graded events. A combination of a few unannounced low-stake quizzes and announced "lower" high-stakes quizzes with one high-stakes exam balanced student study time with performance. While daily student study time decreased in absolute numbers from the 2023 Spring Semester through the 2024 Fall Semester, student performance on exams, when accounting for an increase in testing rigor, likely reveals an increase in student study time efficiency.

The relationship between how much time students study based upon the timing, number, type, and weighting of graded events deserves further study. Regardless, recording students' preparation time is a helpful tool for better understanding student study habits and arranging the course to encourage spaced practice and a healthy work-life balance.

Appendix

Appendix A: Example Time Sheet

Lesson	Example	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16	L17	L18	L19
Date	8/8	DD/MM	DD/MM	DD/MM	DD/MM	DD/MM	DD/MM	DD/MM	DD/MM	DD/MM	DD/MM	DD/MM	DD/MM	DD/MM	DD/MM	DD/MM	DD/MM	DD/MM	DD/MM	DD/MM
1	45																			
2	30																			
3	27																			
4	0																			
5	35																			
6	60																			
7	30																			
8	45																			
9	0																			
10	0																			
11	45																			
12	5																			
13	75																			
14	60																			
15	120																			
16																				
17																				
18																				
19																				
20																				
TOTAL MINUTES	577																			
#CADETS REPORTING	15																			
AVERAGE	38.5																			

Course Student Time Survey

Please enter the total time (in MINUTES) that you spent on ALL ACTIVITIES PERTAINING TO THIS COURSE SINCE THE CLASS LAST MET.

Figure A1: Example Student Study Time Survey Sheet

Appendix B: Survey Questions

B1. Course 1 Survey Questions

Post-semester questions (course 1)

Quiz Instructions:

This short, anonymous "quiz" is an important survey that informs the annual CE450 course assessment process. Please complete the survey with your honest assessment and then acknowledge on your instructor's roster that you submitted your survey. In this manner, your instructor will be able to track your completion of the survey but will be unable to match any survey to a specific individual.

Questions.

All question responses are recorded using a 5-point Likert scale of Strongly Agree (5 points), Agree (4 points), Neutral (3 points), Disagree (2 points), and Strongly Disagree (1 point). Shown

below are the prompts for two survey questions relevant to and referenced in this paper for Course 1.

- Unannounced quizzes increased the amount of time I spent preparing for each class than I would have if there were no such quizzes.
- I prefer fewer unannounced quizzes than more announced quizzes.

B2. Course 2 Survey Questions

Pre-semester questions (course 2)

To master a topic, one must learn (store) information and be able to apply it (retrieve it) when needed. Several teaching practices are included in this course to encourage storage and retrieval of information. These practices will encourage you to space out your learning practice (homework, reading, labs, tests) throughout the semester instead of cramming right before the final. These practices interrupt the "forgetting curve" and have been demonstrated to result in improved memory storage. Additionally, opportunities for recalling information should improve your ability to remember and recall things in the future.

- Short homework assignments will be due weekly to encourage you to work on problems shortly after the material is covered in lectures.
- Frequent quizzes (retrieval practice) will be given in class (with no make-ups available). These will cover textbook reading, previous lectures, and homework topics. Each quiz is an opportunity to practice retrieving stored information.
- Four unit tests and a cumulative final will be given throughout the semester. This encourages spaced study as well as provides additional retrieval practice.
- Homework sets and frequent quizzes will include topics from already-learned material along with newly learned material (interleaving). This promotes long-term remembering as assignments continue to interrupt the forgetting curve.

Questions:

This is a 4 semester-hour course that meets three times per week, 65 minutes each meeting. On average, how many minutes do you anticipate spending in the following areas **in preparation for each 65-minute meeting**? (numeric answer)

- reading related textbook sections
- reviewing previous lecture notes
- completing assigned homework problems
- preparing for quizzes in other ways not mentioned above

On a scale from 1 to 5 (with 1 being no previous experience/low expectations and 5 being lots of previous experience/high expectations), please respond to the following with respect to **weekly homework assignments** (as compared to large assignments due every 3 or so weeks).

- How well do you expect this practice to help you prepare for the unit tests?

- How well do you expect this practice to help you prepare for the final exam?
- How well do you expect this practice to help you remember concepts past this course?
- Describe how your answers to these questions would change if the weekly homework assignments were not graded?

On a scale from 1 to 5 (with 1 being no previous experience/low expectations and 5 being lots of previous experience/high expectations), please respond to the following with respect to **frequent quizzes** (retrieval practice):

- How familiar are you with this practice?
- How well do you expect this practice to help you prepare for the unit tests?
- How well do you expect this practice to help you prepare for the final exam?
- How well do you expect this practice to help you remember concepts past this course?
- Describe how your answers to these questions would change if the frequent quizzes were worth a total of 15% of your grade (instead of only 5%).

Not applicable to this paper, but asked: On a scale from 1 to 5 (with 1 being no previous experience/low expectations and 5 being lots of previous experience/high expectations), please respond to the following with respect to **interleaved homework** and quizzes (where you practice already-learned material along with newly learned material):

- How familiar are you with interleaving?
- How well do you expect this practice to help you prepare for the unit tests?
- How well do you expect this practice to help you prepare for the final exam?
- How well do you expect this practice to help you remember concepts past this course?

End-of-semester questions (course 2)

For each of the practices:

- How well did practice help you prepare for the unit tests? (1-5 scale)
- How well did practice help you prepare for the final exam? (1-5 scale)
- How well did this practice help you remember concepts past this course? (1-5 scale)

Open-ended feedback:
- Describe what kept you from spacing out your review and practice in this course. Also describe why you did not review/read the textbook very much (if this applies to you).
- Several activities were integrated into the course. Please rate them in terms of their effectiveness for learning. When rating them, please keep in mind the level of effort and time required by students and the learning gained for that effort. For each practice a 5 is high/very effective and a 1 is low/not effective.
- Please use this space to clarify or provide more depth to responses to previous questions. What would have been more helpful and lead to increased learning?