ASEE'S VIRTUAL CONFERENCE
At Home with Engineering Education
JUNE 22 - 26, 2020 #ASEEVC
Paper ID #28828

Making Connections: Ensuring Strength of the Civil Engineering Curriculum

Lt. Col. Jakob C Bruhl P.E., U.S. Military Academy

Lieutenant Colonel Jakob Bruhl is an Associate Professor in the Department of Civil and Mechanical Engineering at the United States Military Academy, West Point, NY. He received his B.S. from Rose-Hulman Institute of Technology, M.S. Degrees from the University of Missouri at Rolla and the University of Illinois at Urbana/Champaign, and Ph.D. from Purdue University. He is a registered Professional Engineer in Missouri. His research interests include resilient infrastructure, protective structures, and engineering education.

Making Connections: Ensuring Strength of the Civil Engineering Curriculum

ABSTRACT

A fundamental structural design philosophy is to make connections stronger than the elements they connect. The same must be true within engineering education: the connections between concepts and courses must be stronger (or at least as strong) as the content learned. Teachers are encouraged to create structure for new knowledge, sometimes referred to as scaffolding. This scaffolding, much like shoring for a reinforced concrete building, can only be safely removed when the knowledge structure created by the student has gained sufficient strength, including connection strength. An inability to recall previously learned knowledge is a symptom of an underlying problem: a lack of effective understanding of engineering concepts and principles to then see their application in a new context. In other words, the connections between concepts and applications are weak. To address this underlying problem, civil engineering students at the US Military Academy at West Point were required to solve review problems on each homework assignment in two civil engineering design courses. This paper describes the theoretical underpinnings of these assignments and their implementation. Assessment includes three semesters of academic performance, time spent outside of class, student feedback, and teacher observations.

INTRODUCTION AND MOTIVATION

How many educators are frustrated when students seem unable to recall something discussed in class the previous week? How often are teachers disappointed in their students' ability to identify and correctly apply concepts from prerequisite courses to their current course? How many times do students disappoint their instructors by not seeing how the concept currently being covered builds directly on a concept previously learned? After first teaching CE404 (Design of Steel Structures) and CE483 (Design of Reinforced Concrete Structures), the author responded to each of these questions with: "Quite often! Nearly every lesson! I'm frustrated about this! What can I do about it?" Importantly, it is not instructor frustration that matters most: it is students' long-term success. As Hopkins et al state, "success in some disciplines [engineering among them] depends on students possessing a cumulative body of knowledge and is thwarted by poor retention of foundational content."[1]

This cumulative body of knowledge is often described as knowledge structure and there is a problem: the connections within many students' mental knowledge structure are weak and, therefore, the structure itself is ineffective. As a structural engineer, the author became concerned with the integrity of the structures being built in his students' minds and realized a new design philosophy was necessary for the courses he taught.

The way students organize, or structure, what they learn is critically important. This structure can be visualized as connections between topics or concepts and it is commonly accepted that "students will learn and remember information better if they have many cognitive associations with it; learning of isolated information is more difficult and less permanent than learning of information that is connected to a network of other material."[2(p135)] As students learn new material they relate it to previous knowledge. This is often done subconsciously with students building "sparse, superficial knowledge structures"[3(p45)] but is more effective when done deliberately. Prior knowledge must be activated, sufficient, appropriate, and accurate. Methods to activate accurate prior knowledge include using activities to generate prior knowledge and being explicit in connecting new concepts to prior knowledge.[3(pp31-33)] As a teacher, helping students make correct connections is a vital responsibility. One way to do so is to emphasize differences and similarities of new concepts to ones covered previously in the course or in pre-requisite courses. Lowman explains that "it is difficult to learn ideas that are very similar unless the differences between them are emphasized. Conversely, it is easier to learn disparate ideas if their similarities are emphasized." [2(p135)] Building the structure of knowledge must occur as a student progresses through a program of study. The stronger the connections, the more effective students will be at retrieving and applying prior knowledge to their current course. Beyond college, this ability to retrieve and transfer accurate knowledge will directly affect their professional success.

Developing strong connections requires hard work and, surprisingly, methods of teaching and learning that are not the most intuitive. This is the premise of the book *Make it Stick* which describes the science behind effective learning. The authors explain that learning is most effective when practice is spaced out and subjects are interleaved. While this may feel harder and less productive to students, research shows that it leads to better learning in the long run.[4] There are a variety of benefits of incorporating practice retrieving information. These include improved learning and retention, thinking skills, metacognition, mental organization, and even students' engagement in class.

One method to practice retrieving information is spaced practice. As opposed to blocked, or massed, practice, spaced practice requires students to apply knowledge long after they have been initially learned the knowledge. This idea is not new. For example, Doré and Hilgard, demonstrated its effectiveness at improving retention of psychomotor skills in 1937 and were building on literature that began around the turn of the twentieth century.[5] The topic has continued to be of interest to cognitive psychologists and educators alike. Among the recent contributions to the understanding of spaced practice is that it has a more pronounced effect on simpler tasks and more time between practice sessions improves the effect, regardless of task complexity.[6] In fact, spaced learning has been shown to have little to no effect on immediate recall but is "effective in delayed tests, particularly if they come two to four weeks after learning."[8] In other words, allowing time to forget some details leads to better encoded learning when students refresh their memories by having to apply that knowledge again. This is referred to as "successive relearning" requiring "multiple successful retrievals" over a period of time.[7]

Interleaving describes the practice of including a variety of concepts within an assignment rather than focusing on one concept at a time. While blocked practice may lead to better short term learning, spaced practice and interleaving of concepts leads to dramatic improvement in long-term retention and ability to retrieve knowledge.[9] In a comparison of ten different learning techniques, spaced practice was one of two that showed high utility in improving student learning for a variety of subjects (the other was practice testing).[10] Interleaved practice showed moderate utility with indications that high utility is likely to be shown with additional research.[10] In addition to improving the long-term retention, concentration on the task is also better when practice is spaced. Metcalf and Xu reported that people's minds wandered less in spaced practice when compare to massed practice.[11]

Beyond learning information and being able to retrieve it later, transfer of that knowledge to new contexts is also of critical importance to effective learning. In *How People Learn*, the authors explain that “knowledge that is overly contextualized can reduce transfer” and “all new learning involves transfer based on previous learning, and this fact has important implications for the design of instruction that helps students learn.” [12(p53)] In the same book, they describe factors that influence the ability of students to transfer knowledge to new contexts including: time and method spent learning the concept in the first place, a focus on demonstrating understanding rather than memory of facts, and the contexts in which the concept is applied.

The question left for the teacher is: how can I structure a course and create opportunities for students to interact with the material in ways that improve long-term learning and the ability to transfer knowledge all while ensuring students develop mastery of the course content? This sounds like a tall order and it is. Mirth offers seven specific suggestions for engineering teachers to consider and describes how each is linked to a variety of effective learning strategies. The suggestions are: summary doodling, preclass problems, notebooks, homework, review problems, design problems, and computer analysis.[13] In their discussion about retrieval and transfer of stored knowledge, Felder and Brent discuss the importance of rehearsal to reinforce the schema associated with long-term memory. This rehearsal includes repeated recollection or exposure to the concept along with practicing procedures. Rehearsal improves a student’s ability to retrieve information but also enhances transferability. Exercises of rehearsal can and should be integrated into class meetings. These may include “assignments that call for applying the procedure in different contexts, and explicit statements of conditions that make one procedure more appropriate than another for a particular type of problem.” [14(p71)]

This is important: well-crafted assignments provide students with opportunities to interact with the material in a way that leads to long-term retention along with improved ability to retrieve information and apply it to new contexts (that is, transfer). Doing so leads to mastery which requires students to acquire and integrate component skills and know in which context it is appropriate to apply those skills. In other words, mastery is about more than an ability to demonstrate application of something covered in class. To facilitate mastery in students, teachers must diagnose weak or missing component skills among their students and provide isolated practice of those skills. To facilitate transfer, opportunities to apply knowledge in diverse contexts and prompts to relevant knowledge should be provided.[3(pp117-120)]

Those missing component skills can be developed through requiring students to review applicable prerequisite knowledge. In an engineering context, this can be accomplished by assigning review problems, an idea which has been explored by other educators. For example, Mirth included review problems beginning in the fifth week of a statics and dynamics course requiring students to review material they were introduced to earlier in the course.[13] Feedback from students was positive but there was no assessment of the effectiveness of the review problems on learning. Butler and Marsh demonstrated the effectiveness of integrating repeated retrieval practice, spacing, and timely feedback in an upper-level electrical engineering course. Their study focused on spacing practice of content within the course and found that doing so “boosted student learning and retention in the course.”[15] Hopkins et al incorporated questions from previous content within a precalculus course on quizzes throughout the semester and found student performance on the final example improved by 5% compared to those who did not experience this spaced practice. Importantly, they also found that students who employed spaced practice in this course performed better in the follow-on calculus course, as measured by exam scores and final course grade.[1] These three examples included only review of concepts from the course in which the students were enrolled but not concepts from prerequisite courses. These are remarkable as being among the few studies that have investigated spaced practice in actual classroom settings rather than the laboratory and all but one focused on the effect on the early stages of learning (i.e. within the course in which they were originally learned.)

THE IDEA

Based on the literature about spaced practice and interleaving and encouraging examples from engineering and math classes, the guiding question for this study became: could civil engineering homework assignments be crafted in such a way as to prompt students to recall relevant knowledge from previous courses, provide them with an opportunity to apply that knowledge in a new context, and thereby improve their mastery of current course material?

Creating assignments in this way aligned with our department's model of teaching and learning: instructors provide structure for new knowledge, connect new to previous knowledge and use a variety of learning activities while students take ownership of knowledge development within an environment that provides opportunities to practice and apply knowledge.[16] Motivated by this aspiration along with the science behind effective long-term learning and transfer of knowledge, the integration of review problems into homework assignments came to mind as one way to address the question. Doing so had several objectives: (1) encourage development of mastery of course concepts by ensuring foundational concepts were understood, (2) emphasize to students how concepts covered in a current course build on concepts from prerequisite courses, and (3) provide opportunities for students to practice fundamental engineering concepts.

Short review problems were included on most homework assignments in CE404 (Design of Steel Structures) in Spring 2019 and CE483 (Design of Reinforced Concrete Structures) in Fall 2018 and Fall 2019. These two courses were specifically chosen because students anecdotally viewed the primary goal of these courses as learning how to navigate a design code or specification and were not clearly seeing connections to underlying engineering mechanics. This was demonstrated by poor performance on preliminary steps required within homework assignments and by an inability to recall important concepts in class.

Review topics for each assignment were carefully chosen to relate to material covered in class shortly after the assignment was due. This was done to ensure the prerequisite material had been reviewed prior to it being needed in class. This also decoupled review material from the new course topics on the assignment, effectively interleaving concepts across multiple assignments. For example, on the first assignment for CE404, the assigned review problems focused on axial behavior, specifically tension, requiring only knowledge that students had learned in a previous course. While students worked on this assignment outside of class, the topics being covered in class included steel manufacturing, basic material science, and structural plans reading. The date the assignment was due corresponded to a lesson introducing steel tension member behavior. Thus, students were required to review prerequisite material about axial tension behavior before applying that knowledge in class. In general, the concepts included as review problems on one assignment were connected to concepts being applied to the current course material on the next assignment. Review topics and current course topics included on each homework assignment for CE404 and CE483 are summarized in Table 1 and Table 2, respectively.

Table 1 CE404 Problem Set (PS) Assignment Topics Covered

PS	Review Topics Covered	CE404 Topics Covered
1	Axial behavior (tension specifically)	Material properties, plans reading
2	Column behavior (buckling)	Analyze and design truss members (tension only; include connecting element)
3	Beam behavior; calculate area moment of inertia and stresses due to bending	Analyze and design truss members (focus on compression but review tension too)
4	Frame analysis (computer analysis; check by hand)	Analyze and design beams
5	Combined loading; failure criteria	Beam-column design
6	None	Frame analysis; single welded connection problem

As shown in Table 1, CE404 included six homework assignments. These varied in point value from 65 to 150 points for a total of 600 points out of a 2000-point course. The review problems accounted for 20-50% of the points on each assignment depending on the complexity of the problems.

Table 2 CE483 Problem Set (PS) Assignment Topics Covered

PS	Review Topics Covered	CE483 Topics Covered
0	Concept Inventory - mechanics	None
1	Load case combinations and load path for floor systems; shear and moment diagrams; flexural normal stress and strain distribution for rectangle cross-section	Reinforced concrete basics; mix design
2	Shear and moment diagram for an indeterminate beam; flexural normal stress and strain for T-beam	Reinforced concrete flexure theory
3	Load path for floor system and columns	One-way slab analysis and design
4	Shear stress in beams	T-beam analysis and design
5	Indeterminate axial; combined loads	Floor system design (slab and beam; including shear)
6	Soil capacity calculations	Prestressed beam
7	Beam deflections; axial deformation (indeterminate)	Column analysis and design
8	None	Structural design (slab, beam, girder, column, footing)

As shown in Table 2, CE483 consisted of eight conventional homework assignments plus a "Problem Set 0" which was a multiple-choice concept inventory of applicable mechanics concepts for completion credit. It was intended to provide feedback to students at the beginning of the term to help them identify topics that they should review. This concept inventory was not included in the original implementation of review problems in the Fall of 2018. It was added in Fall 2019 as the instructor realized that making students aware of specific prerequisite knowledge that would be applied in the course through a formative assessment might motivate students to review concepts with which they were shaky prior to needing that knowledge in the course or having to employ it on a summative assessment. Effectively, this was another attempt at interleaving and spacing practice of important fundamental engineering mechanics concepts.

For the eight assignments in CE483, point values varied from 75 points to 100 points for a total point value of 700 points out of a 2000-point course. The review problems accounted for about one-third of the points on each assignment.

THE IMPLEMENTATION

Given the theoretical underpinnings of these assignments, it was important to let students know why they were being required to solve problems using only content covered in previous courses. Explanation was provided to students at the start of the term as a paragraph within the syllabus and discussed in the first class meeting. The philosophy described for students was:

> Your engineering curriculum is comprised of a series of courses that cover a variety of engineering concepts. These concepts do not belong only to the course in which you learned them. In fact, most of them apply broadly across civil engineering. Recognizing these connections is an important part of your education and will enable you to solve complex problems that you have never seen before. To assist you in making connections, most problem sets in this course include several problems that require you to apply what you have learned in previous courses. In each case, the knowledge you need for these problems will not be covered in class but will be applied in class after the problem set is submitted.

Explanation was reinforced on each homework assignment along with hints about where students originally learned the material and how those concepts were connected to the current course. For example, instructions provided for CE404 Problem Set 3 stated:

> The [review] problems … have been selected to reinforce the concepts of beam behavior – a topic you were introduced to in MC300 and have applied in MC364 and CE403. Your mastery of this fundamental concept will enable more effective learning of new material in this course.

When describing the requirements for individual review problems during the first implementation of this idea in CE483 in Fall 2018, no specific hints were provided to students. For example, one problem on CE483 Problem Set 4 required students to:

> For an internal shear force of 1000-lb, draw the shear stress distribution through the depth of the plain concrete rectangular cross section shown in [figure of the cross section]. On

the stress distribution, label critical points and their associated values, in psi, (i.e. maximum and minimum).

Student feedback complained about spending a lot of time trying to recall in which courses they had learned the concept being reviewed, and therefore where to begin looking for notes and textbooks to refer to. This was a legitimate complaint that needed to be addressed. Clear prompts are important for helping students effectively and efficiently connect knowledge, so hints were provided in subsequent semesters. For example, a sentence was added to the end of the above problem stating “HINT: remember learning about shear stress in MC300?”

As described above, student solutions of review problems were due before the topic was applied in the current course. For the example about shear stress above, the class meeting in which this problem was due was a lesson on calculating shear strength of a reinforced concrete beam. One of the first topics covered in that lesson was a brief review of shear stresses in an isometric rectangular cross-section and the concept of average shear stress. This led immediately into a discussion of the various shear resistance mechanisms in a reinforced concrete beam and simplified methods to calculate the design shear strength. The next homework assignment included several problems requiring students to calculate shear strength of reinforced concrete beams of various cross-sections. The connection between what students had previously learned about theoretical shear stress and how the concept was simplified to apply to shear strength of reinforced concrete beams was made clear through the combination of review problems, in-class instruction, and subsequent homework assignments over a period of two weeks.

THE ASSESSMENT

Initial assessment focused on answering three questions:

(1) Did students understand the purpose?
(2) How much time did this require of students?
(3) What influence on learning did this have?

The first question was important from a metacognition perspective. The author wanted students to be aware of how people most effectively learn. The second question was important as completing review problems would likely take time away from applying new course material. The third question was very important because the author’s hypothesis was that the completion of problems reviewing content covered in previous courses would lead to more in-class engagement and better understanding of course concepts.

Did Students Understand the Purpose?

Students understood and appreciated the purpose of the review problems as they related to the current course material. A few positive statements from students’ end-of-course anonymous surveys included:

1. They were helpful and served as an effective foreshadowing of topics to come in the future.
2. I think it was a good thing to add. I kind of liked having to pull out my old notes to solve the problem.

3. They help me become more comfortable with previous material that I had a hard time recalling.

The first comment was very encouraging because the student had clearly made the connection that these review problems were directly applicable to future learning in the course. The other two comments were also encouraging as it was clear students appreciated having to review previous material and saw the value in it, even though it may have been difficult.

In the anonymous end-of-course feedback, students also provided some ideas to make the review problems more effective. A few of these included:

1. More explanation in class on how the previous knowledge applies to what we are learning in class.
2. I think a quick explanation on why the review problems will be beneficial in the future because it is not always obvious.
3. Directly state what lessons or classes review material is sourced from, as well as the associated resources (teachers, books, etc.) to reference while solving the problem.
4. A little bit of review beforehand may prove helpful, simply because it's been a year and a half since we've seen some of that material.
5. Providing a review of those concepts in class or in slides on blackboard. Many of the concepts I had forgotten and it took some time and digging in old notes to find them.
6. It would be fun if students had the opportunity to teach review problems to their classmates at the beginning of class when we review the problem set we just got graded.
7. I would suggest not going back so far as MC300/MC364 for some of them. I spent far too long on 7, 8, and 10 point questions than the point values justified. And I still got 3 or 4 points taken off.

From the above examples, the first two suggest that the explanation provided within the assignments should be clearer and better reinforced in class. This agrees with a statement by Lohman that instructors should design assignments to be "closely aligned with their overall course objectives and integrate them with what is happening in class sessions at the time."[1(p228)]

The third comment indicates that for some students, the hints provided were inadequate. In a few cases, the hints were very specific, pointing to a section out a textbook for example. In most cases, however, the hints were general, pointing only to the course in which the concept was covered. Finding the right balance between providing enough of a prompt to avoid unnecessary time searching through unrelated material while still making the review something the student accomplishes is a challenge.

Comments 4 and 5 indicate that students would prefer the instructor to provide the review for them. While this is understandable, cognitive science indicates that this would be less effective for long-term learning than forcing students to struggle through the review themselves. The author does not intend to provide any formal review in class or through provided material. However, future explanation of the review problems will include discussion about the value of the struggle to review prior knowledge.

The sixth comment is a clever idea for a few reasons. First, it would provide students with an opportunity to explain to their peers, in their own words, technical concepts. Second, it would reinforce the importance of the concept. And, third, it could be used by the instructor to lead directly into in-class coverage of how that concept relates to the current course.

The final comment is from a student who did not understand the purpose. MC300 and MC364 cover statics and mechanics of materials. Most review problems relied on content from these because understanding how fundamental mechanics principles apply to the design of steel or reinforced concrete structures is vital. This comment reinforces that the explanation for why the topics are being reviewed must be made clearer and more effective on the assignment and in class. The frustration with point values is an ongoing challenge. Points assigned to problems should reflect their difficulty and / or expected amount of time to solve. However, considering that these problems covered content previously learned, the instructor allotted them fewer points on the assumption that they would be less difficult and take less time than problems requiring application of new knowledge. For many students, this was a faulty assumption: they spent much more time on these homework assignments than in previous semesters.

How Much Time Did This Require of Students?

Each day, at the start of class, the instructor circulated an anonymous survey asking students to record the number of minutes they spent on the course since the last class meeting. This was intended to gather information about how much time students spend preparing for class, completing assignments, and studying for exams. It was used by faculty to help them assess if the requirements for the course are reasonable. Too little time being reported by students and the faculty may consider increasing requirements; too much time, and the faculty member should consider reducing requirements. Collecting this information has been a habit within our department for decades. For 3.0 credit courses, the target for time spent outside of class is 120-min between each lesson. For 3.5 credit courses, this target is 150-min. It is generally accepted that courses should expect less than this given the other competing requirements on student time. When courses exceed these targets, the instructor has likely made the course too demanding for the credits allocated.

The first semester in which review problems were included in CE483 (Fall 2018, 19-1) saw a sharp increase in reported time: up over 65% from the previous semester, as seen in Figure 1. There was one other contributing factor that may have led to the increase. In previous years, students took CE404 and CE483 concurrently. Both design courses are demanding, but students only have a limited amount of time that they can devote to academic work. Students in CE483 in Fall 2018 had taken CE404 the previous semester (18-2). The increase in reported time spent in CE404 between 18-1 and 18-2, seen in Figure 2, indicates that students were able to devote more time to the course because they were not taking it concurrently with CE483.

Noting the increase in time reported in CE404 between 18-2 and 19-2 (Spring 2019, the first semester review problems were implemented in CE404) suggests that the time required to review (and for some students likely re-learn) was more significant than the instructor assumed. Providing more specific hints and guidance was included in CE483 in Fall 2019 (20-1) and the reported time decreased slightly.

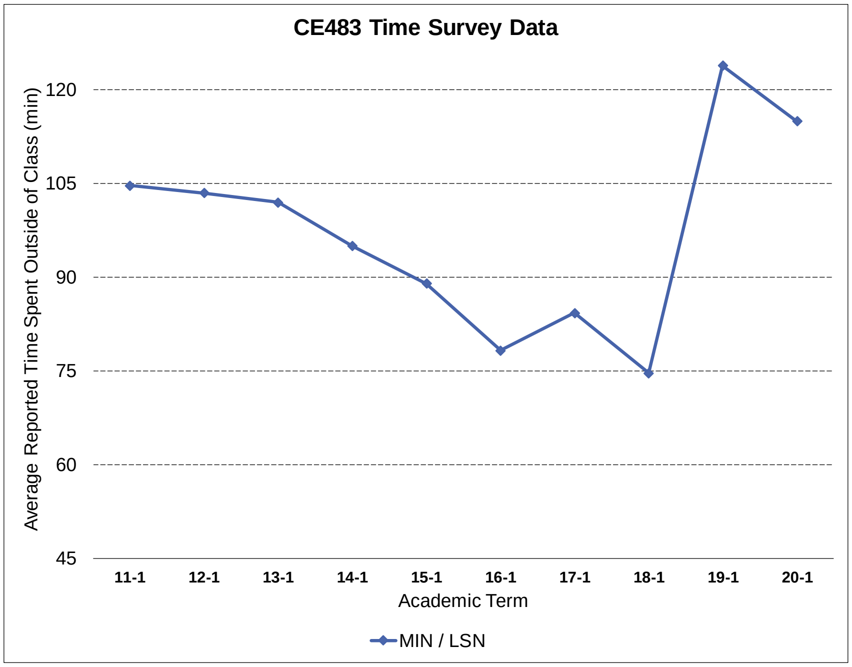


Figure 1 Historical Time Reported Spent Outside of Class by Students in CE483

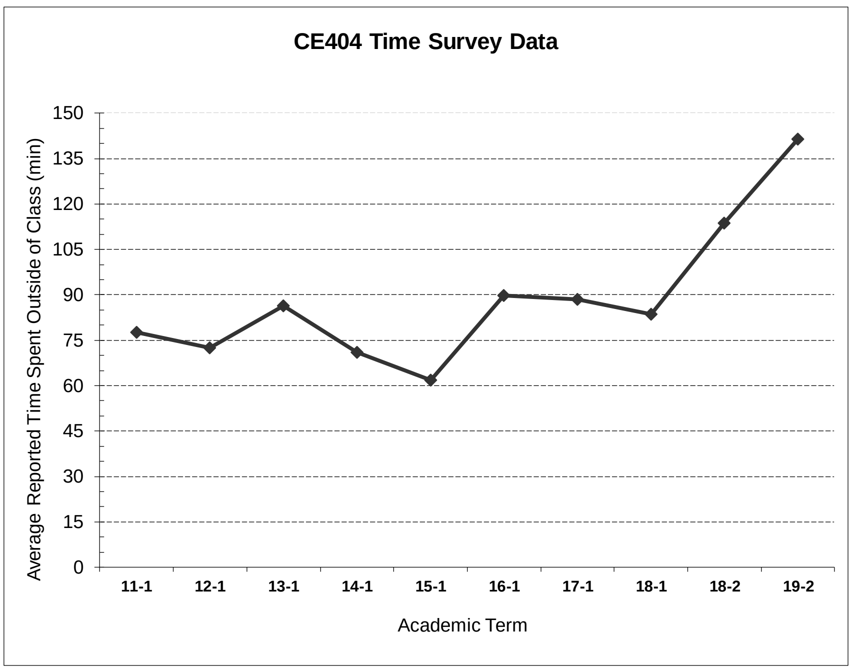


Figure 2 Historical Time Reported Spent Outside of Class by Students in CE404

What Influence Did This Have on Learning?

Recognizing that students understood and appreciated the review problems was encouraging. Realizing that completing the review problems appeared to increase the amount of time they were spending on the course outside of class was important. Did the time and effort spent on these review problems have any impact on student learning? One way to answer to this question was to examine course performance. The course average for the past ten years for CE404 and CE483 is provided in Table 3 and Table 4, respectively. Comparing 18-2 to 19-2 for CE404 suggests that there was a decline in performance. However, students in 19-2 had a lower incoming grade point average (GPA) than in 18-2 and this likely contributed to lower performance in the course. When normalized by dividing by the incoming GPA, it appears that there was improvement from 18-2 to 19-2. It is impossible to say that performance in the course improved because of the addition of review problems. There are a variety of influences: different instructors, the homework problems changed, and the mid-term exams changed slightly.

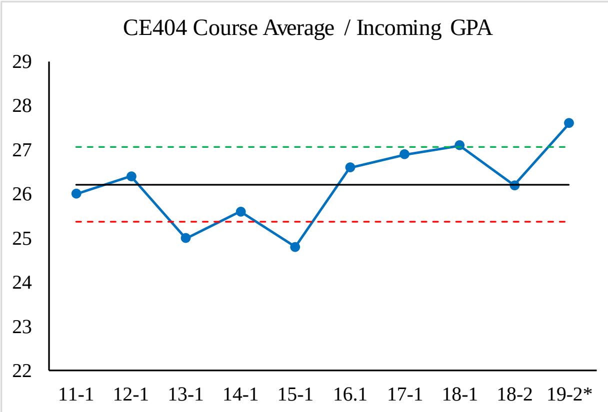
To better isolate the influence that review problems may have had on academic performance, a more effective measure is the course term end exams (TEE). These exams do not change (with very minor exceptions) from semester to semester and are typically graded using the same cut-scale. This makes final exams a very good measure of the influence of new learning techniques or strategies at our institution.

Table 3 Academic Performance Measures for CE404

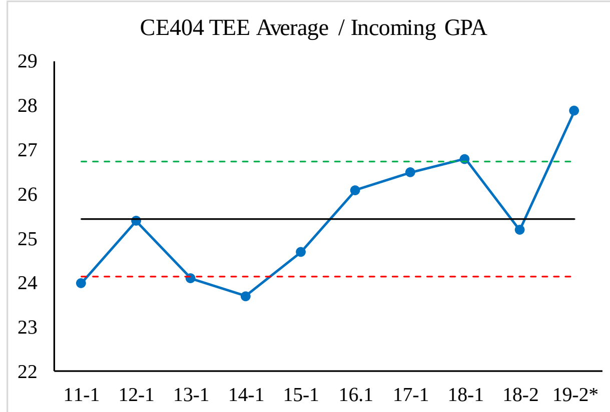
Term	Course Average	TEE Average	Average Incoming GPA	Course Avg / Incoming GPA	TEE Avg / Incoming GPA
11-1	84.5	78.0	3.245	26.0	24.0
12-1	82.6	79.7	3.133	26.4	25.4
13-1	84.3	81.3	3.367	25.0	24.1
14-1	82.1	75.9	3.210	25.6	23.7
15-1	86.1	85.7	3.470	24.8	24.7
16-1	85.6	84.2	3.220	26.6	26.1
17-1	87.8	86.5	3.270	26.9	26.5
18-1	86.4	85.4	3.184	27.1	26.8
18-2	87.1	83.7	3.320	26.2	25.2
19-2*	86.0	87.0	3.113	27.6	27.9
$\bar{x}$	**85.3**	**82.7**	**3.253**	**26.2**	**25.5**
σ	**1.8**	**3.6**	**0.103**	**0.9**	**1.3**

* review problems were included on homework assignments

Normalizing for incoming GPA accounts for academic aptitude difference between semesters. Figure 3 depicts the results from the last ten terms. The solid black line is the ten-year mean and the dotted red and green lines are one standard deviation below and above the mean, respectively. Normalized performance in 19-2 (with review problems) was almost two standard deviations above the 10-year average while 18-2 (without review problems) was average.



(a) Final Course Grade



(b) Term End Exam

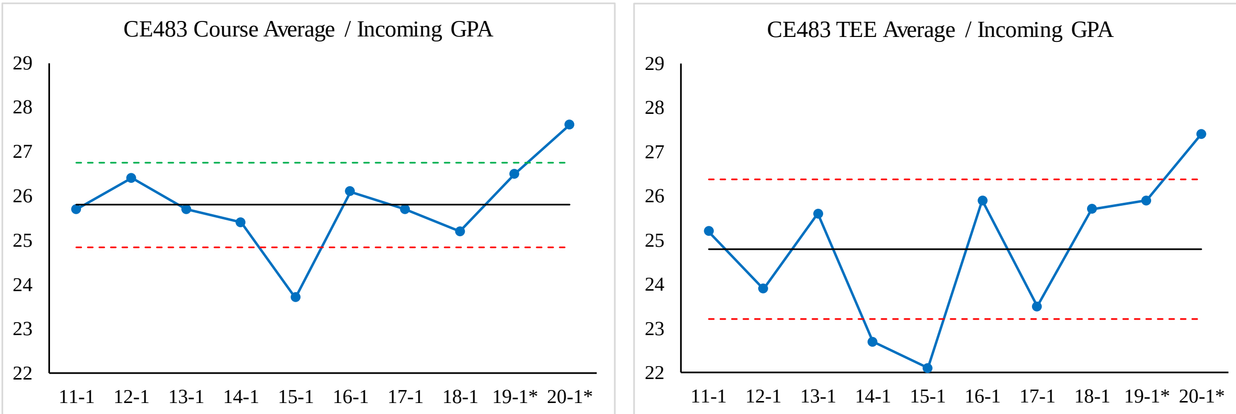
Figure 3 Academic Performance Measures for CE404, Normalized by Incoming GPA

The same observation can be made when examining the performance in CE483, summarized in Table 4 and graphically in Figure 4. Normalized course average and TEE grade were above average in 19-1 (the first semester in which review problems were included). Importantly, after modifying the way review problems were described and prompts written, and with a group of students who had completed review problems in both CE404 and CE483, the normalized course and TEE averages were well above one and a half standard deviations from the 10-year average.

Table 4 Academic Performance Measures for CE483

Term	**Course Average**	**TEE Average**	**Average Incoming GPA**	**Course Avg / Incoming GPA**	**TEE Avg / Incoming GPA**
11-1	83.4	81.9	3.245	25.7	25.2
12-1	82.6	74.7	3.133	26.4	23.9
13-1	86.1	85.9	3.354	25.7	25.6
14-1	81.9	73.0	3.220	25.4	22.7
15-1	80.9	75.5	3.407	23.7	22.1
16-1	84.5	84.0	3.237	26.1	25.9
17-1	83.7	76.4	3.259	25.7	23.5
18-1	82.0	83.7	3.252	25.2	25.7
19-1*	85.8	83.7	3.235	26.5	25.9
20-1*	85.5	84.8	3.094	27.6	27.4
$\bar{x}$	**83.6**	**80.4**	**3.244**	**25.8**	**24.8**
σ	**1.7**	**4.6**	**0.086**	**0.9**	**1.6**

* review problems were included on homework assignments



(a) Final Course Grade (b) Term End Exam

Figure 4 Academic Performance Measures for CE483, Normalized by Incoming GPA

THE FUTURE OF THE IDEA

The initial implementation was successful and encouraging and will be continued in CE404 and CE483. In fact, it is being implemented in CE404 in semester 20-2 by a different instructor. The author intends to employ the inclusion of review problems on homework assignments in other courses he teaches and will continue to gather data to better understand answers to the three questions described in the assessment above.

The largest area of concern concerns time. This must be monitored carefully and better ways to understand how much time is being spent by students on review problems should be considered. For example, rather than circulating an anonymous survey in class after the fact, perhaps students could record how much time they spend on the two portions of the assignment ((1) review problems and (2) new topics) directly on their submitted work.

To improve efficiency of relearning, clear “hints” should be given for each review problem. Not only should this reduce the time spent trying to find information about this concept being reviewed, but when written well, such “hints” will also help students explicitly understand how content from specific prior courses applies to the current course. This will improve the knowledge structure that students create while completing the curriculum.

To better quantify the influence of review problems on academic performance, a more thorough data analysis will be conducted in each course in which review problems are included. This will include a by-student analysis of performance on mid-term exams and the TEE, normalized by incoming GPA or other measures determined to be more appropriate. By completing statistical analysis of each semester population, a more complete understanding of the effect on learning can be developed. Some of this analysis could possibly be completed on data from previous semesters if detailed enough records were maintained by the faculty who taught the courses in those terms. Given the positive effect indicated in this study, the author is hesitant to use control groups in which some students do not complete the review problems.

To understand if this activity has longer lasting effects on knowledge retention after the students have completed the courses in which review problems are a part, the Fundamentals of

Engineering Exam (FEE) results will be analyzed. All students in the civil engineering program at the US Military Academy are required to take the FEE as a graduation requirement. Looking at aggregate performance in topic areas relevant to those for which review problems were focused, such as mechanics of materials, and for those courses in which review problems were incorporated, will help understand the effect on long-term retention. Of course, there are many other contributing factors to FEE performance that would have to be considered in this analysis.

CONCLUSION

Students understand and appreciate the purpose of including review problems on homework assignments. It appears that the addition of these requires more time from students outside of class but has important academic benefits, particularly as measured on final exam performance.

To effectively implement review problems within a course a few principles can be applied:

1) Carefully choose concepts which connect clearly to future course material.
2) Clearly explain the philosophy behind including review problems so students understand the purpose and expected influence on learning. Be sure to tell them about the frustrations they may experience.
3) Discuss concepts covered on review problems in class shortly after they are completed by students to ensure connections to current course content are clear.
4) Explain to students the science behind spaced practice and interleaving to aid in metacognition and encourage students to consider these concepts in their self-study learning strategies.[10,17]

Realizing that this is effective within a course, it is worth considering across the curriculum:

1) Include problems requiring students to apply concepts from previous courses on assignments in every course that depends on prerequisite knowledge.
2) Coordinate across courses typically taken by students in the same semester to avoid unnecessary duplication of review problems. When possible, make connections between courses being taken concurrently on homework assignments and in class.

Employing a method like this helps ensure that connections between concepts covered in prerequisite courses are strongly made to concepts within the current course. This will assist students in building a sound structure for the important knowledge they gain across the curriculum. Just as the strength of connections within a structure has a dramatic influence on the strength and behavior of that structure, requiring students to review prior knowledge in a meaningful manner will help them develop knowledge structures that will last for years – not just within their academic preparation but in professional practice.

REFERENCES

1. Hopkins RF, Lyle KB, Hieb JL, Ralston PAS. Spaced Retrieval Practice Increases College Students' Short- and Long-Term Retention of Mathematics Knowledge. *Educ Psychol Rev*. 2016;28(4):853-873. doi:10.1007/s10648-015-9349-8

2. Lowman J. *Mastering the Techiniques of Teaching*. 2nd ed. San Francisco, CA: Jossey-

Bass; 1995.

3. Ambrose SA, Bridges MW, DiPietro M, Lovett MC, Norman MK. *How Learning Works: 7 Research-Based Principles for Smart Teaching*. San Francisco, CA: Jossey-Bass; 2010.

4. Brown PC, Roediger HL, McDaniel MA. *Make It Stick: The Science of Successful Learning*. Cambridge, MA: The Belknap Press of Harvard University Press; 2014.

5. Doré LR, Hilgard ER. Spaced practice and the maturation hypothesis. *J Psychol Interdiscip Appl*. 1937;4(2):245-259. doi:10.1080/00223980.1937.9917535

6. Donovan JJ, Radosevich DJ. A meta-analytic review of the distribution of practice effect: Now you see it, now you don't. *J Appl Psychol*. 1999;84(5):795-805. doi:10.1037//0021-9010.84.5.795

7. Rawson KA, Dunlosky J, Sciartelli SM. The Power of Successive Relearning: Improving Performance on Course Exams and Long-Term Retention. *Educ Psychol Rev*. 2013;25(4):523-548. doi:10.1007/s10648-013-9240-4

8. Dempster FN. The Spacing Effect: A Case Study in the Failure to Apply the Results of Psychological Research. *Am Psychol*. 1988;43(8):627-634. doi:10.1037/0003-066X.43.8.627

9. Agarwal PK, Bain PM. *Powerful Teaching: Unleash the Science of Learning*. San Francisco, CA: Jossey-Bass; 2019.

10. Dunlosky J, Rawson KA. Practice tests, spaced practice, and successive relearning: Tips for classroom use and for guiding students' learning. *Scholarsh Teach Learn Psychol*. 2015;1(1):72-78. doi:10.1037/stl0000024

11. Metcalfe J, Xu J. People Mind Wander More During Massed Than Spaced Inductive Learning. *J Exp Psychol Learn Mem Cogn*. 2016;42(6):978-984. doi:10.1037/xlm0000216

12. Committee on Developments in the Science of Learning. *How People Learn: Brain, Mind, Experience, and School (Expanded Edition)*. Washington, D.C.: National Academies Press; 2006. doi:10.17226/9853

13. Mirth JA. A specifications-based approach for the design and delivery of a statics/dynamics course. In: *ASEE Annual Conference and Exposition*. Tampa, FL: American Society for Engineering Education; 2019. https://peer.asee.org/31998.

14. Felder RM, Brent R. *Teaching and Learning STEM*. San Francisco, CA: Jossey-Bass; 2016.

15. Butler AC, Marsh EJ. Integrating Cognitive Science and Technology Improves Learning in a STEM Classroom Author (s): Andrew C . Butler , Elizabeth J . Marsh , J . P . Slavinsky and Richard G . Baraniuk Source : Educational Psychology Review , Vol . 26 , No . 2 , Special Issu. 2018;26(2):331-340.

16. Wambeke B, Barry BE, Bruhl JC. Teaching Model as a Living Document. In: *ASEE Annual Conference and Exposition*. Columbus, OH: American Society for Engineering Education; 2017. https://peer.asee.org/28924.

17. McGuire SY. *Teach Students How to Learn: Strategies You Can Incorporate Into Any Course to Improve Student Metacognition, Study Skills, and Motivation*. Sterling, VA: Stylus Publishing; 2015.