Problem Set Zero

What these students were good at…was feeding back correct answers: they had mastered the arts of short-term memory and recall. The whole class was a wonderful example of what the British call “surface learning.” But very little “deep learning”—which comes with time, depth, practice, and reinforcement—seems to have occurred.¹

This section of a keynote address by Theodore J. Marchese at the 1998 conference of the American Association for Higher Education gets right to the heart of a problem many educators face: which teaching techniques can encourage students to master course content. As professional engineers, we understand that our students’ success in the professional practice of engineering is contingent on their ability to remember and apply critical skills years after they learned them in school. As professional educators, our success in teaching these skills in the classroom is contingent on the students’ ability to remember and apply critical skills months after they learned them in the classroom. Clearly the former does not occur without the latter, and the latter, according to Marchese and others, is an elusive goal. This paper explains a technique developed and implemented by several Civil Engineering faculty members teaching structural mechanics, analysis, and design at the United States Military Academy in the Spring, 2009 and the Fall, 2009 terms to encourage mastery of critical skills and transfer of these skills to subsequent courses. The concept is called “Problem Set Zero” to stress the fact that the material being evaluated is from the prior course(s) and must be mastered before a student begins Problem Set One.

1. Introduction

1.1 Curriculum Structure

A common feature of Civil Engineering and other curricula is the establishment of prerequisite courses which allow students to progress from basic math and science to fundamental mechanics, and then to engineering design courses. A student’s education culminates in a capstone experience designed to integrate these parts into a coherent whole. As students progress from term to term, the courses they take require a constantly increasing baseline of knowledge gained and skills developed in previous courses. The success with which a student can perform the prerequisite skill and can apply the prerequisite knowledge will affect his or her performance in the current course. Entrance into a follow-on course is predicated on successful completion of the previous course, which is measured through exit exams. Success on an exit exam does not guarantee retention of material and the ability to apply it in follow-on course. In fact, instructor observations and student feedback over multiple years have indicated that our students were not carrying critical skills forward. This deficiency resulted in short reviews of carry-over material becoming detailed re-teaching of basic concepts at the beginning of each new block of material. Though students demonstrated a familiarity with the concepts,
they consistently were unable to execute problems correctly. Unable to move forward without a solid foundation of student expertise, teachers had no option but to devote precious classroom time to reviewing material. As instructional time is a precious, limited resource, this situation is clearly not conducive to the achievement of all of the programs objectives.

1.2. Related Literature on Conceptual Retention and Mastery

A fundamental principle of education is that students remember something of what they learn. Numerous published research efforts have attempted to identify the effect of key variables on the ability of students to retain material. This background informed the development of the Problem Set Zero concept.

The question of how quickly students begin to lose information and skills is worthy of consideration when attempting to increase information retention. In a 1993 study by Semb, Ellis, and Araujo, retention was tested at four and eleven months after the block of instruction. In two differently administered tests, scores from the four month tests dropped an average of 18% on questions of recognition, recall, comprehension and mental skills. At eleven months, the test average dropped 22% from the initial test. The additional drop-off between four and eleven months was just 4%, indicating that most of the retention loss occurs quickly. In another study, attendees of a clinical research orientation seminar were tested on the content of the program following completion and again after four months had passed. The attendees were divided into subsets of those who had used the knowledge or skills during the interim and those who had not. Predictably, those who had employed the content of the seminar and tests outperformed those who had not by about 8%.

Students’ retention from prerequisite courses was specifically tested in another study which considered the performance of tasks at different taxonomy levels. This study, conducted by physiology faculty from 11 institutions, considered the performance of students on factual versus application level recollection of items previously learned. Students’ performance on factual questions was 19.8% better than the performance on application questions. Several other studies also show greater skill/memory decline over time for application or computational items than for knowledge items. This would seem to present a significant obstacle to retention across an engineering curriculum, where the majority of the education is application based.

Semb, Ellis, and Araujo concluded that the teaching style initially employed can have some influence on retention. Specifically, students studying in a system of instruction in which they completed many iterations of each problem showed better retention than students learning in a more conventional style. Marshall B. Jones defined the term “overpractice” as the amount of additional practice that a subject is given after correct performance has been achieved. Jones’ overpractice concept recognizes that while the amount of learning decreases with each repetition, the amount of overpractice relates positively with retention, suggesting that although no or very
little new learning occurs, each additional repetition increases the future retention of the skill.\textsuperscript{4} In both studies, more repetitions promote better retention.

An application of the high repetition study is the concept of mastery learning, the principal defining characteristic being the establishment of a criterion level of performance which demonstrates a mastery of the subject. Students are repeatedly assessed until the mastery level is achieved, with additional instruction as required. The mastery learning approach requires the organization of time and resources to ensure that most students are able to master instructional objectives.\textsuperscript{5} Wankat and Oreovicz supported the theory, citing that “since we want our graduates to be able to produce an essentially perfect design, it made sense to require them to be “perfect” in at least part of their undergraduate education, and mastering material before studying the next material has to increase aptitude.” \textsuperscript{6}

Angelo and Cross discussed classroom assessment techniques in their 1993 book.\textsuperscript{7} Problem Set Zero builds upon the concept of their background knowledge probe, an assessment of a student’s level of knowledge or understanding prior to a course, seminar, or lesson. Angelo and Cross propose that the background knowledge probe can be used by the instructor to tailor the lessons in order meet the students where they are.\textsuperscript{7} Student learning is improved because there are no gaps between the understanding the students bring to class and the starting point of the professors’ instruction.

1.3 Problem Set Zero

The objective of Problem Set Zero is to facilitate student retention and transfer of critical material from prerequisite course to follow on courses. While built around a problem set, this concept involves more than just assigning some extra homework problems. It builds on the best practices available in teaching and learning literature. Following Wankat and Oreovicz ,\textsuperscript{6} it requires students to produce and essentially perfect solution. After Slavin, Jones, and Semb, Ellis, and Araujo\textsuperscript{2}, it provides further opportunity for repetition and overpractice to facilitate mastery learning. It encourages retention through summer and winter breaks to address the retention loss identified by Semb, Ellis, and Araujo.\textsuperscript{2} It is similar to the Background Knowledge Probe, but also substantially different. The purpose of the Background Knowledge Probe is to allow an instructor to assess the knowledge level of the students and modify the instruction accordingly. The purpose of Problem Set Zero is to provide students with an assessment of their prerequisite skills and a vehicle to recall, relearn, and master those skills for application in the new course.

Application of this concept begins with identification of critical skills that students must retain and transfer to ensure success as they progress through the curriculum. This is not the same as determining what should be taught in a particular class because some topics taught in a class are terminal in that class—they are not applied or required in subsequent classes. For example, singularity functions are taught in our structural analysis course but not used directly in
any follow-on courses while shear and moment diagrams appear in at least five courses in the curriculum. Once these skills are selected, they are identified to the students in the course of instruction as essential for success in the current course and in a specific follow-on course or courses. Problems are selected which will allow students to demonstrate mastery of these concepts and are provided to the students at either the end of the pre-requisite course or the beginning of the follow-on course. Within the first few lessons of a new course, students complete and submit Problem Set Zero. Grading is binary—each problem is either completely right or it is wrong. Correct answers receive full credit and wrong answers are returned to the student for correction and resubmission. Students re-submit Problem Set Zero until all problems are performed correctly. Each submission results in a reduced grade, but ultimately a correct solution. Not everyone gets an A, but everyone gets the right answer.

In the Fall Term of 2009 the Problem Set Zero concept was applied in two different course sequences in the Civil Engineering Program at the United States Military Academy. Section 2 of this paper describes the application of Problem Set Zero to facilitate transfer of knowledge from CE300, Fundamentals of Engineering Mechanics and Design, to CE364, Mechanics of Materials. Section 3 explains the use of Problem Set Zero in the integrated structural design sequence to facilitate transfer of knowledge from the analysis course to the design courses and assist in unifying these three courses.

1.4 Student Demographics

The effectiveness of Problem Set Zero is evaluated by comparing the results from the Fall Term of 2008 where Problem Set Zero was not used to the Fall of 2009 where it was. Fortunately, the demographics of the populations are similar enough to allow an honest comparison between subsequent fall academic terms. The details of the populations are specified below:

<table>
<thead>
<tr>
<th></th>
<th>Students</th>
<th>Ladies</th>
<th>Gentlemen</th>
<th>Incoming GPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall 2008</td>
<td>171</td>
<td>7%</td>
<td>93%</td>
<td>3.23</td>
</tr>
<tr>
<td>Fall 2009</td>
<td>152</td>
<td>9%</td>
<td>91%</td>
<td>3.08</td>
</tr>
</tbody>
</table>

Table 1A: Mechanics of Materials (CE364) Study Populations

<table>
<thead>
<tr>
<th></th>
<th>Students</th>
<th>Ladies</th>
<th>Gentlemen</th>
<th>Incoming GPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall 2008</td>
<td>44</td>
<td>9%</td>
<td>91%</td>
<td>3.13</td>
</tr>
<tr>
<td>Fall 2009</td>
<td>67</td>
<td>9%</td>
<td>91%</td>
<td>3.25</td>
</tr>
</tbody>
</table>

Table 1 B: Design of Reinforced Concrete (CE483) Study Populations
2. Application of Problem Set Zero to Basic Mechanics Course Sequence

2.1 Course Descriptions

Within the civil engineering curriculum, the first two engineering courses presented are CE300, Fundamentals of Engineering Mechanics and CE364, Mechanics of Materials. As will be shown, the material covered in these courses is designed to be cumulative in nature, with basic concepts introduced in CE300 and then expanded upon and brought together during CE364. As a first course, CE300 introduces students to static force analysis, the concepts of stress and strain and the mechanical properties of various engineering materials. Mechanics of Materials takes each of the concepts presented in CE300 and takes them forward. For each loading type, both statically indeterminate and inelastic behaviors are considered. Loads are considered in combination, with both two and three dimensional stress transformation used to determine the critical internal stress states. Student understanding of material behavior is expanded and material science fundamentals are considered. All of these concepts are tied together in Mechanics of Materials through analysis and design problems, with students able to apply the tools of classical mechanics to a variety of physical problems. A summary of the progression of concepts from CE300 to CE364 is presented in Table 2 below.

<table>
<thead>
<tr>
<th>CE 300 Course Concepts</th>
<th>CE364 Course Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Equilibrium</td>
<td>Three Dimensional Static Equilibrium</td>
</tr>
<tr>
<td>Stress-Strain Diagrams</td>
<td>Shear Stress – Shear Strain Diagrams</td>
</tr>
<tr>
<td></td>
<td>Introduction to Material Science</td>
</tr>
<tr>
<td></td>
<td>Elasto-Plastic Assumption</td>
</tr>
<tr>
<td>Axial Loading</td>
<td>Statically Indeterminate and Inelastic Axial Loading</td>
</tr>
<tr>
<td>Beam Bending</td>
<td>Statically Indeterminate and Inelastic Beam Bending</td>
</tr>
<tr>
<td>Torsion of Circular Shafts</td>
<td>Statically Indeterminate and Inelastic Torsion</td>
</tr>
<tr>
<td>Analysis and Design for a Single Load</td>
<td>Analysis and Design due to Combined Loading</td>
</tr>
</tbody>
</table>

Table 2: Progression of Concepts from CE300 to CE364

2.2 The Problem of Retention

The success of CE364 is tied to student retention of material presented in CE300. Students are generally scheduled to take CE300 in the spring semester of their second year and CE364 the following fall. There are, however, roughly 20% of the students taking CE364 each year who have waited for more than a year since they took CE300. With at least three and as many as eighteen months between courses, it is predictable that students will have forgotten some of the concepts they need to be successful. In anticipation of this, each major new concept in CE364 is prefaced with a short review of critical material. These review sessions were intended to simply present the pertinent relationships and rely on student initiative to address shortcomings in understanding. These results from course feedback, shown below, were selected to demonstrate that the short reviews had mixed results:

- “Slow down the pace. I felt overwhelmed throughout this semester.”
- “Make the course so it does not reteach CE300.”
- “Don't repeat so much from CE300.”
- “Spend more time on some of the harder topics, like the 3-D loading.”
Clearly, a number of things were happening. Firstly, the limited reviews were insufficient to assist those students who completely forgot the material from CE300. Instead of reviewing one topic and then building on it, struggling students perceived that two different topics were being presented within a short time. This problem was exacerbated by the fact that less time was available to introduce the newer, more complex topic. Simultaneously, instructors lost the attention of the brighter and better prepared students who did not need a lengthy review of material they had already learned.

During the course assessment process, the teaching team considered how to address the problem of student retention. Fundamentally, all instructors agreed that it is the student’s responsibility to retain key concepts taught during a course. Whatever solution was chosen, it must focus on placing the primary responsibility on the student. There was also agreement that a review of concepts rather than the mechanics of solving problems could be accomplished quickly and with good effect without detracting from the day’s material. Finally, it was important that whatever method was applied, it not add to the student’s plate in terms of assignments.

2.3 Application of Problem Set Zero

The method chosen to address the issue of retention was “Problem Set Zero.” Students were assigned a problem set covering material completely presented in CE300. They received the assignment prior to the first lesson of class, and were given an opportunity at the beginning of the semester to ask questions outside of class before submitting their assignment. The first few lessons in any engineering course are generally devoted to administration and introduction of new concepts, so student workload during this time is light. Also, it is the time in the semester when a student is closest to the material from the last semester and can therefore recall it most clearly.

The focus of the problem set was critical engineering skills needed to correctly apply the concepts learned in CE300. The entire problem set was designed to take the typical student 30 minutes to complete, and each problem was selected to make the concept review that occurred during each block of instruction easier to execute. The problem types were chosen for review because they are building blocks for more complex stress analysis. If students have not mastered them, they will be unable to progress successfully in CE364. They are:

- Shear and Moment Diagrams
- Properties of Areas (Centroid, Composite Moment of Inertia, Polar Moment of Inertia, First Moment of Outward Area)
- Stress Strain Diagrams
- Basic Torsion Analysis

By moving review of these basic skills into Problem Set Zero, at least 30 minutes of teaching time would be saved per topic. Considering the four subjects reviewed in the problem set, a total of two class hours, or 5% of the total teaching time in the course was saved. Students were expected to complete the problems using their CE300 notes, and instructors were available to answer questions as required.
Importantly, another new facet was introduced to the students in this problem set. Students would continue to work the problems until they got each individual problem correct. If students failed to execute a problem correctly, they received a new problem of the same type that they then needed to execute to standard. For some students, this meant working a problem type three or more times until they correctly completed the assignment. This repetition was intended to reinforce to students the necessity of retaining information as they progress through the engineering curriculum, as well as showing them the importance of being correct in their calculations. An 80% design is wrong in industry, so accepting that as a final product sets a dangerous precedent for the student.

2.4 Assessment by Benchmark Events

A danger in teaching is the introduction of new requirements that have negligible effects. The desire to innovate is, in itself, admirable. However, an honest evaluation of one’s efforts must occur at some point to avoid burdening students unnecessarily. Given the heavy workload expected of students at the United States Military Academy, this was of prime concern to the instructors in CE364. The efficacy of the problem set was therefore measured through student feedback, instructor feedback and numerical analysis of student performance on graded events. Data was collected from each of the 143 students taking Mechanics of Materials in fall 2009, and compared with historical data for prior classes as compiled during the course assessment process.

The variables considered in the analysis are as follows: student final grades in CE300, number of re-dos required for each problem type on Problem Set Zero, and performance on similar tested problems in CE364. Before discussing the results, it is worthwhile to explore the limitations of an analysis based on a single semester of collected data. The first problem is one of population size. By analyzing student performance by CE300 final grade, we found that the sample population of students with A and B grades was far larger than for lower grades, as might be expected in an entry level course. There were 68 students with A grades, 58 students with B grades, 19 students with C grades and only three students scoring a D or lower. As data continues to be collected across years, a more balanced data set will likely be compiled. However, as we are limited by the timing of the analysis, it is worth considering the initial results and comparing them to historical performance.

Firstly, students were segregated by performance in CE300 and the number of iterations required for each critical problem type to achieve a correct solution. The overall trend shown in Figure 1 below is predictable. Students in the A range generally needed only one opportunity to correctly complete the problem set, with the number of iterations increasing as final grade decreased.
What is more interesting, perhaps, is the fact that even students below the A level required, on average, two iterations or more on low-difficulty review problems after only a few months away from the material. This is consistent with the retention issues found by Semb, Ellis, and Araujo. For the calculation of section properties, the majority of the sample population was unable to complete a problem correctly the first time. Problem Set Zero, therefore, can act as a valuable diagnostic tool for instructors to gauge student performance early in the semester before major graded events have occurred as well as indicate to the students themselves areas they need to review and restore proficiency.

Analysis was also conducted on student performance on similar graded events within CE364. The representative problems considered were design of a circular shaft subjected to torsion and calculation of section properties, as evaluated during the two timed exams in the course. Individual student work was considered while group work was excluded to eliminate the positive effects of collaboration on student performance, and also to see how well students performed when needing to use skills quickly. Figure 2 below shows student grades for each problem type compared against their CE300 final grade. A trend line was added to depict a one to one CE300 performance to graded results in CE364 ratio, which would indicate no improvement or lowered performance over skills established in the pre-requisite course.
Examination of student results yielded interesting findings. While the critical task of calculating properties of areas appeared to generally follow the expected trend in relation to CE300 grades, the results for the torsion problem are more encouraging. Performance at the A+ level overall is below what the trend line would predict. This can be explained by the difficulty of improving scores at the top margin. Performance of students in the B and C ranges were flat, and for low B and C students tested performance was higher than what might be expected. Variations in the C- to D spectrum can be attributed to small population size. From this, it appears that the numerous repetitions provided through Problem Set Zero were most useful to the band of students in the B and C range that struggle when presented more challenging concepts.

The final method chosen to examine student performance was a simple comparison of the course average on test questions versus prior years. These results are shown in Table 3 below:

<table>
<thead>
<tr>
<th>Academic Year</th>
<th>Torsion Problem Course Average (%)</th>
<th>Properties of Areas Course Average (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>77.8</td>
<td>83.1</td>
</tr>
<tr>
<td>2007</td>
<td>72.2</td>
<td>72.7</td>
</tr>
<tr>
<td>2008</td>
<td>75.8</td>
<td>83.2</td>
</tr>
<tr>
<td>2009</td>
<td>81.7</td>
<td>89.2</td>
</tr>
</tbody>
</table>

Table 3. Historical Comparison of Student Performance

Though results are preliminary, a comparison with historical performance, considering a total population size of 700 students spread over four years shows that student performance jumped significantly in 2009. Given a curriculum that does not vary from year to year
significantly and an instructor population that has an appropriate balance between veteran and new instructors, it appears that Problem Set Zero improved overall performance significantly over prior years. Both the performance of students in the B and C range rose in the current year against expected performance and the average performance of all students was markedly higher than in the three prior years.

2.5 Assessment by Student Feedback

Although consideration of student performance is a valuable indicator of the efficacy of a new method in teaching, feedback from the student is also meaningful. Student views were compiled through the dissemination of a minute paper to all students at the mid-point in the course, and through exit interviews with a cross-section of students during faculty counseling sessions near the end of the term. The results of the minute paper are summarized in Table 4 below:

<table>
<thead>
<tr>
<th>Minute Paper Question</th>
<th>Student Rating (1-5, 5 being excellent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>How helpful was PS #0 in preparing you for more advanced topics in CE364?</td>
<td>3.63</td>
</tr>
<tr>
<td>Was it better to execute PS#0 at the beginning of the course, rather than at mid-point (yes or no)</td>
<td>80.3% Yes Response</td>
</tr>
<tr>
<td>Do you have better mastery of the topics in PS#0 after working them until complete?</td>
<td>3.94</td>
</tr>
</tbody>
</table>

Table 4. Student Responses to Mid-Course Minute Paper

A selection of student comments from the minute paper are also included below:

- “I felt like it was far too picky about being 100% correct. Sometimes I never know my mistakes.”
- “It helped me to remember how to find I, Q, etc…. I looked back at it last night.”
- “As an individual who had difficulty with Problem Set Zero initially, reworking the problem set really helped cement the ideas.”
- “It was helpful. I am glad it was at the start of the semester so I had time to re-work the problems on it.”
- “For me I didn’t remember anything from CE300 so it was an excellent review and helps me to better understand the material.”
- “Delaying it until we start using the covered material would make sure it is fresh in our minds.”
- “Problem Set Zero was so long ago and there was so much material in this block that I don’t think it had an effect at all.”

Consideration of both the rating and the comments demonstrated that students seemed to buy into the idea of reviewing key elements of the material as a way to facilitate better understanding in the course. Interestingly, many students acknowledged that they failed to retain critical skills from CE300, and expressed that working problems multiple times allowed them to master the material. The only point of real disagreement lay with the placement of the problem set during
the semester. In fact, an alternate approach suggested by students would be to integrate a review element to homework assignments throughout the term that would prepare students for the next block of instruction, rather than reviewing all the material at the beginning. Changing the timing of the problem is worthy of further consideration. Increasing student workload later in the semester, however, may lead to degraded results as review competes with new material for student study time.

Questions asked during exit interviewing focused on determining student understanding of the purpose of Problem Set Zero, and any suggestions for inclusion of additional course material. When discussing the purpose of exercise, students clearly understood the linkage between CE300 and CE364, and the role of the problem set as a retention tool. What was interesting was many different ways students perceived instructor intent for the assignment. Verbs such as remind, refresh, force, remember, evaluate, demonstrate and help were used by students in their purpose statements. Additionally, not a single student mentioned the importance of correctly solving problems, which was a major facet of the assignment. It appears that communication of intent by instructors needs to be more carefully considered, and reinforcement of these themes must carry on beyond the first assignment. Students across the entire spectrum of grades agreed that the problem set helped them during the course, and only a few additional topics were introduced as being worthwhile to include in future years. Taken as a whole, student feedback indicates a positive perception of the assignment, and also shows that it reinforced the importance of retaining material between courses.

2.6 Assessment by Faculty Perceptions

The teaching team for CE364 consisted of five instructors each teaching two sections, of whom three had taught the course before. Only one instructor was in his first year of teaching. All instructors agreed that the problem set freed up time in class to be able to teach the new material more completely. Having worked through simple problems, students were also better prepared to receive the conceptual review. Another positive to come from the problem set was the ability to directly expect that students be able to execute basic skills correctly. Because the problem set was repeated, even students who normally would perform poorly had executed a problem at least one time correctly. In fact, the process of evaluating the students at the very beginning of the semester also acted as an excellent diagnostic tool to determine those students who needed more attention in order to grasp the course material.

The two instructors who taught CE364 for the first time this year expressed skepticism about the efficacy of the repeated submissions in getting marginal students to improve their performance. In practice, the reissue of the problem set was halted after four iterations due to the fact that those students who were not getting needed to be taught the material, rather than simply work problems. This occurred for a number of instructors, and is borne out in the data collection. What was not observable to the new instructors, however, was the overall improvement of all students in comparison to past years.

From a grading perspective, it is undeniable that the work load for instructors at the beginning of the semester increased, and this was borne out in the faculty comments. Attention will be given to the number of iterations executed for this assignment. Decreasing the number of iterations of the problem set or using a web-based or more carefully written evaluation could decrease the instructor work load.
3. Application of Problem Set Zero to Integrated Structural Design Course Sequence

3.1 Course Descriptions

One of the more difficult semesters for students in the civil engineering program at the United States Military Academy is the first semester of their senior year. In addition to being the start of their senior year, this semester begins the transition from analysis of structures towards the more difficult process of design using four different materials: steel, concrete, masonry, and wood. What seems to make this transition even more difficult is the continued review of structural analysis and mechanics which accompanies teaching the two primary design courses, Design of Reinforced Concrete (CE483) and Design of Steel Structures (CE404). Students tend to spend so much time focusing on relearning the mechanics and materials and trying to recall how to use structural analysis software that they often cannot focus on the new material being presented through the course. During Structural Analysis (CE403), a committed effort began to integrate these classes together by establishing the idea that these three courses were in reality one 9.5 credit hour course taught in 3 class hours separated by a summer. The principle integrating concept is the Load and Resistance Factor Design (LRFD) design philosophy expressed by “Design Strength greater than or equal to the Effects of Loads.” The LRFD design equation of $\phi R_n \geq \Sigma \gamma_i Q_i$, affectionately known as “The Million Dollar Equation,” ties the courses together with CE403 focusing on the $\Sigma \gamma_i Q_i$ side and CE404 and CE483 calculating the $\phi R_n$ side. Problem Set Zero was used to communicate the important concepts from CE403 that the faculty expected the students to have mastered prior to beginning CE404 and 483.

CE403, Structural Analysis, addresses the analysis and design of basic structural forms such as beams, trusses, and frames, which are found in bridges and buildings. Classical deflection techniques such as direct integration and virtual work; and indeterminate analysis techniques such as the force method and displacement methods (slope deflection, direct stiffness and moment distribution) are used to determine forces and deflections in elastic structures. Structural analysis computer programs are introduced and directly applied in the solution of graded analysis and design problems. Approximate analysis techniques are used to check the general accuracy of computer-based results.

CE404, Design of Steel Structures, teaches the engineering thought process through the design of steel structures. The course synthesizes the fundamentals of statics, mechanics of materials, and structural analysis and applies them to the design of structural members, with emphasis on satisfying real-world needs. Topics include an introduction to the design of structural systems, design of steel tension and compression members, design of beams and beam-columns, and an introduction to connection design. All design is performed in accordance with codes and specifications used in current engineering practice. A comprehensive design problem requires development of a design methodology, consideration of alternative solutions, and design of an optimal steel structure to meet stated functional requirements.

CE483, Reinforced Concrete Design, introduces the materials and mechanical properties of concrete, and the design of reinforced concrete structures. Mix design and strength testing labs develop the concept of proportioning constituents for quality concrete and provide a background in techniques of material testing, quality control, and sound construction practices. The study of reinforced concrete includes analysis and design of simple structures, resulting in an appreciation
for the strength and serviceability of these structures. Current codes and standards are used to
guide the practical design of beams, slabs, columns, and footings.

3.2 Critical Skills List

The course directors for CE483 and CE404 identified the key concepts in their courses,
and then determined which of these concepts were taught in Structural Analysis. Questions for
the problem set were developed from these key concepts. From this approach, the following
concepts were identified:

1. Use structural analysis software to determine required shear, moment and axial loads on a
structure.
2. Identify load paths and resolve loads on a structure.
3. Apply the Minimum Design Loads for Buildings and Other Structures: ASCE Standard 7-05,
in order to determine the applied loads on a structure.
4. Draw a shear and moment diagram for a complex loading and support condition given applied
loads and support reactions.
5. Understand the relationship between applied load, shear, and moment.
6. Apply LRFD in order to determine the critical load case combination acting on a structure.
7. Calculate deflections based on the virtual work equation.

3.3 Application of Problem Set Zero

Problem Set Zero was distributed to the students on the final lesson of CE403 in order to
prepare them for the idea that it was coming on lesson number one of the following semester.
The students had a week without classes prior to departing for their summer training, and during
this time, some of students began to work on the problem set with the idea of getting it done
while the information was still fresh in their heads. Additional instruction was provided to three
students and some even accessed online videos from CE403 prior to departing for their summer
details.

Once the students returned from the summer, they had an additional week without classes
prior to beginning the semester, and all of them received an email reminder about the problem
set during this time. On lesson one, the Problem Set Zero was officially distributed with lesson
three as the due date for the first submission. Subsequent submissions did not change content at
all, but in order to get everyone to complete the work accurately, it took four submissions and
lasted for over a month. The first two submissions were completed entirely as a hard copy
submission completed by the students on the date required. In order to decrease the grading
requirement of the faculty and time commitment by the students, submission number three
required the students to re-submit only the questions which they did not get entirely correct on
their first submission. The fourth and final, submission was a student-teacher conference which
allowed more direct contact with those students who continued to struggle with the material.

The problem set was worth 100 points in both CE404 and CE483 which accounts for 5%
of the overall grade, and grading was done on a binary scale. The intent was to focus the
students on getting the correct answer as opposed to their continued focus on partial credit, and
to ensure that it was worth enough points to make it worth their time and effort. At the same
time, the faculty wanted to make it a positive experience where the worst they could do was
below the average from the previous year, but not enough to completely destroy their grade if
they did not do well. This resulted in the floor for the grades given and the development of the
faculty conference in order to ensure those still struggling with these key concepts understood
them.

<table>
<thead>
<tr>
<th>Submission Number</th>
<th>Format</th>
<th>Grade if Entirely Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>Paper</td>
<td>100%</td>
</tr>
<tr>
<td>Second</td>
<td>Paper</td>
<td>95%</td>
</tr>
<tr>
<td>Third</td>
<td>Paper</td>
<td>85%</td>
</tr>
<tr>
<td>Fourth</td>
<td>Faculty Conference</td>
<td>80%</td>
</tr>
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</table>

Table 5. Problem Set Zero Grade Scheme

3.4 Assessment by Benchmark Events

One expected outcome was the fact that those with better grades in CE403 did better on
Problem Set Zero. Figure 3 reports the average number of iterations it took to complete the
problem set as compared to final grades in CE403. It is clearly seen that those who did well in
CE403 did better on Problem Set Zero. Of note is the fact that no one got the entire problem set,
which consisted of ten questions, correct on the first submission, but of those who missed only
one or two questions on the problem set, six out of the seven got an A- or A+ in CE403. Those
who did well in CE403 did seem to learn the material better and had an increased recall when
asked to complete Problem Set Zero.

![Iterations of Problem Set Zero versus CE403 Final Grade](image_url)

Figure 3. Number of Submissions versus CE403 Final Grade

Figure 4 also shows this to be the case. It contains the full breakdown of the first three
submissions by final grade distribution in CE403, and shows that students who earned an A- to
A+ in CE403 did better on Problem Set Zero on their first submission. The interesting category
in this graph is the B+ group which performed worse than the C+ group for the first and second submissions, and the fact that the students who studied abroad, the “O” category in Figure 4 outperformed the students who got a C or D in CE403. These students generally have better grades, so the ability for them to teach themselves is higher, and they demonstrated their resolve to working towards the correct solution. None of them had any introduction to the structural analysis software used, prior to starting the problem, so this seemed to be their primary deficiency on Problem Set Zero. All nine did that problem incorrectly on their first submission, and six of them still had it wrong on their second submission. By the third submission, all of the grade categories had achieved a 90% correct rate, and the primary question that everyone continued to need to review was the structural analysis software.

Figure 4. Total Questions Correct (Maximum of 10) versus CE403 Final Grade

Figure 5 below demonstrates that the opportunity to complete the second submission helped those in the middle of the grading scale from CE403 the most. The data in the figure is standardized based on the average improvement, measured by number of questions missed, seen from the first submittal to the second. The average number of questions missed per student decreased by 2.86, so completing the problem set the second time did help everyone, but it specifically seemed to help some students more than others. Students who earned a between a B+ and C all saw a larger increase in their improvement from the first to the second submission when compared to the rest of the course. The general conclusion is that getting an A or higher in a course means that you have learned the material to a superior level, and that these students will improve their performance, as seen above, but they will not have such a huge improvement when compared to the rest of the course when the material is revisited.
Problem Sets 1 and 2 in CE483 were essentially the same in term 09-1 when Problem Set Zero was not used and term 10-1 when it was. Table 6 shows the percentage of students achieving an A- or B- grade and reviews the student performance on these two problem sets over the past two course offerings. It generally shows that the students did better on the initial review material. Problem Set 1 reviewed LRFD and the Million Dollar Equation with a focus on how it was developed and why it is used in order to design members to resist load effects. In term 09-1, the students did well on this problem set with 16% earning an A- or above, but after using Problem Set Zero with term 10-1, the number doubled to 33%. The numbers also saw an increase down to the B- level. In term 09-1, 59% of the students earned a B- or above on this problem set, while in term 10-1, 70% achieved this grade. Problem Set 2 had the first problem dealing with entirely new material, but some of the problem set dealt with load case combinations and calculating load effects. There was no improvement on those who earned an A- or above on this problem set, 39% in both terms, but at the B- level the number of students jumped from 66% in term 09-1 to 76% in term 10-1. The immediate effects of doing Problem Set Zero definitely helped to review the LRFD and load effects calculations which were extremely important at this point in the course.

<table>
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<tr>
<th>Academic Year</th>
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<th>Problem Set 2</th>
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<tr>
<td></td>
<td>% of students earning</td>
<td>% of students earning</td>
</tr>
<tr>
<td>2008 (w/o Problem Set Zero)</td>
<td>A’s 16% B’s 59%</td>
<td>A’s 39% B’s 66%</td>
</tr>
<tr>
<td>2009 (w/Problem Set Zero)</td>
<td>A’s 33% B’s 70%</td>
<td>A’s 39% B’s 76%</td>
</tr>
</tbody>
</table>

Table 6. Historical Comparison of Student Performance

3.5 Assessment by Student Feedback
Problem Set Zero was assessed through two primary methods from student feedback. The first was getting an understanding of how well the students felt they understood the material on a scale from one, being absolutely no understanding, to nine, complete understanding, prior to and after completing the Problem Set Zero process. Three primary specified tasks were identified to be measured: Structural Analysis Software, Loads and Load Case Combinations, and LRFD. In each of these areas, the students assessed their understanding as a net increase from prior to beginning the semester as seen in Figure 6, before completing problem set zero, to include the fact that no student felt they had decreased their understanding. The largest increase was seen in LRFD which improved from an assessment of 4.68 to 6.72, an increase of 2.04. This was the lowest assessment for understanding prior to entering the semester, but what is of note is that even for the topics the students felt they understood, primarily Loads/LCC, saw an increase of 1.24 to 8.08.

![Student Assessment](image)

**Figure 6. Student Assessment**

The largest individual gains on understanding were seen primarily by students who had studied abroad the previous semester. The unique opportunity presented through the timing of Problem Set Zero during this semester is that several students choose to study abroad during their second semester of their junior year. Problem Set Zero was seen as a way for them to re-integrate with their classmates, get an opportunity to understand what their classmates had studied during the previous semester, and to get an idea of what they would need to study on their own if they did not sufficiently learn the material covered in the problem set.

On lesson ten, a survey was distributed to the students to obtain their initial reaction to Problem Set Zero. Overall, the feedback from the students was positive, and they understood the purpose. Generally, the students appreciated the opportunity to get additional help on these subjects. Two sample responses of truly understanding the idea are seen by the following comments, “To be able to use (analysis software) and basic concepts such as LCC, million $ equation and virtual work” and “To ensure that we retained/relearned critical material from CE403 that is necessary for this 9.5 credit hour course.” The students understood that they did not remember all of the key concepts from the previous semester, and they generally saw this as
an opportunity to refresh their memory on what they needed to learn and know. The biggest complaint was that they saw it as a “haze” or “to waste our time.” This dealt directly with the concept of having to repeat the problem set until it was entirely correct.

3.6 Assessment by Interview

At the completion of CE483 and CE404, interviews were conducted on a range (both in grade and performance on Problem Set Zero) of students in order to gain their perspective on the overall Problem Set Zero concept now that they had some time to reflect on CE483 and CE404 as a whole. Over ten percent of the class (eight students) was interviewed, and the overall consensus was that the concept behind Problem Set Zero is a good one that will help students remember material that is easily forgotten when not practiced during their summer training. The common quote was that it was a “good refresher” on the material they had forgotten over the summer. The students’ recall of the material on the problem set was good, and they specifically stated that the review of the structural analysis software and the calculation of load effects using ASCE 7-05 and load case combinations were the two primary key concepts that they needed to review. No additional key concepts from CE403 were identified, but half of the students felt that some review of Mechanics of Materials (CE364) and Statics (CE300) might be useful since they are both essential to their success in CE483 and CE404.

The interview process also identified the application of virtual work to calculate deflections as unnecessary within CE483 and CE404, so its inclusion on Problem Set Zero was not required. The students did not like the way that the grading was handled. Specifically, they did not like the idea that they had to get the problems entirely correct in order to receive credit. They understood the concept and why the faculty was requiring this, but it was something new to them. Over time, the students will adjust to the idea that they must get the entire problem set correct, but they proposed several additional solutions. The best one dealt with grading each problem separately and providing a grade on that question which would count towards their total. This would reward those who spent the time to work on the problem set by giving them full credit on the problem they did correctly while still maintaining the faculty focus on binary grading.

3.7 Assessment by Faculty Perceptions

The faculty had an overall positive outlook of the concept. Each instructor and professor had noticed the lack of recall for their students immediately following a long summer of training, and Problem Set Zero addresses that directly with the idea of preparing them for class. The additional gain was to see the students starting to work on the first day of class and getting a jump start on the coursework. The primary concerns of the faculty centered around two things: grading time and the focus on topics from CE403.

The grading was meant to be somewhat simple because of the binary grading, but the students needed some feedback as to where they had gone wrong, and this took time to provide. In addition, the subsequent submittals required time. As the grading began to wear on later into the semester, the instructors began to get tired of seeing the same students making the same mistakes on the same problems while trying to grade new problem sets that were being assigned.
Problem Set Zero should be completed early in the semester and hopefully, prior to the assignment of additional work. Once the new coursework was assigned, Problem Set Zero became more of a detriment to current learning than a useful tool to prepare the students to learn. They did not seem to make any progress towards a correct solution at some point, and the learning reached a point of diminishing returns. This continued work also tended to detract from the students desire to learn. The individual additional instruction sessions with each of those who did not complete the problem set by their final submission did help to demonstrate the faculty’s desire to see them succeed, but this again took time to sit down and have a conference with each one of them.

In addition to the grading concern, CE483 and CE404 take concepts from several classes and combine them together to develop the general design concept. This being the case, not all of the required key concepts were primarily taught in CE403, so some of the problem set should include material from classes other than just CE403. If the focus is going to be on preparation for the upcoming courses, then the problem set needs to look further back to key concepts in other classes that will help in the successful completion of the course. Much like the students, the faculty felt Problem Set Zero should include additional key concepts that will greatly increase student recollection and learning prior to getting into the coursework.

4. Conclusion

4.1 Overall Assessment

From the faculty and student perspective, both the concept and application of Problem Set Zero in the fall of 2009 was successful. As shown through the assessment of selected benchmark events, the impact on student learning was most significant for those performing in the B and C range of the grading scale. Assessment through student interviews and minute papers indicates that students understood the purpose of Problem Set Zero and saw personal benefit to completing the exercise. Faculty members looked positively on the experience, but had several constructive comments to manage both the grading load and the challenges posed by students unable to correctly solve the problems after three attempts. Problem Set Zero will continue to be used and assessed in the upcoming year. The authors are curious to see how students respond to their second experience with Problem Set Zero.

4.2 Relationship to Literature on Retention and Mastery

Problem Set Zero is an extension of the existing literature on retention and mastery. Following Wankat and Oreovicz \(^6\), the requirement that the work be done correctly without error proved challenging and frustrating to students, but introduced them to the idea that engineering designs must be correct. Additionally, all students produced a correct solution where a grade of 80% indicated the number of attempts to achieve the correct solution rather than 80% of the work being correct and 20% being wrong. Consistent with Slavin \(^5\), Jones \(^4\), and Semb, Ellis, and Araujo \(^2\), the review and repetitive aspects of Problem Set Zero provides an opportunity for ‘overpractice,’ encourages mastery, and promotes retention over the summer breaks. Problem Set Zero’s contribution to the literature is that it, in an explicit manner, unites different courses in
a curriculum, informs students of essential prerequisite skills, and provides a method for assessment and mastery of those skills.

4.3 A Model for Applying Problem Set Zero

Problem Set Zero is applicable for use between any two courses where skills from one course are directly transferred to a follow-on course without re-teaching or extensive review. Development and implementation proceed along the following lines:

- **Identify critical prerequisite skills to transfer between courses.** This cannot be everything in the course and must be specific skills or tasks that will be applied directly in the follow-on course and can be stated in the form of homework problems. From our experience, about five seems to be a good number. For more advanced courses, it may be necessary to go back to more than one course. For instance, in our program, calculation of composite body properties is taught in CE300, reinforced in CE364, not used at all in CE403, and then reappears in CE404 and 483. This could be a Problem Set Zero topic in both CE364 and CE404/483.

- **Brief the class on Problem Set Zero.** Since one purpose of Problem Set Zero is to integrate courses in the mind of the student, it must be introduced and explained to students in the prerequisite course. Students must understand that in Course B they will receive a homework assignment consisting solely of problems from Course A. Additionally, they must understand the grading rubric, especially if binary or mastery grading is used.

- **Administer and grade Problem Set Zero.** Problem Set Zero should be handed out on the first day of a course and submitted very early in the term while the overall student workload is low. The problem set should be returned within 48 hours so that students can begin the second submission.

- **Return, resubmit, re-grade, and terminate.** Continue the submission and grading process until mastery is achieved, no further learning is occurring, or resources cannot support the continuation of the process. One key decision is whether problems should remain the same or change as re-submissions are required.

Perhaps the most challenging aspect of this concept is instructor commitment to grade, return, and re-grade the assignment until mastery is achieved. Selection of a grading rubric that can minimize the burden on the grader and encourage mastery is essential. Key points in establishing the rubric include:

- **Establish a grading plan where the all students are required to perform the work correctly and the grade is based on the number of iterations.**

- **Will grading be based on individual problems or the problem set collectively?** Our experience indicated that grading each individual problem and requiring the re-submission of only incorrect problems is the preferred method.

- **How many submissions will be allowed?** Our experience indicates that more than four submissions would be counterproductive to both students and faculty.

- **Will the grading and feedback rubric change with subsequent submissions?** The faculty conference between the 3rd and 4th submission to provide additional instruction to
struggling students employed in CE483 proved effective from both the student and faculty perspectives.

4.4 Conclusion

The issue of student retention of critical material is not new. In the mid 1800s, Father John Bosco, in writing and talking with his students said, “The third means of success in studies consists in getting used to not going on in any subject…without knowing the previous material well.” In his discourse, Father Bosco quoted Cicero (b.104 B.C., d. 43 B.C.), “Tantum scimus quantum memoria retinemus”—We know as much as we retain in our memory.” Even so, it is not correct to say that this is a 2000 year old problem. It is simply a problem that re-occurs with each new generation of students. As teachers, we constant strive for techniques to address this issue with our current students.

Problem Set Zero provides one method for educators to use in making connections between courses, reinforcing fundamental skills, and encouraging mastery of material. It is well grounded in teaching and learning literature and our experience has shown it to be effective from both the student and instructor perspectives. It is adaptable to a wide variety of topics and courses and to the needs of students and instructors. It requires an investment of time from both the students and the teachers, but this investment is repaid with improved student participation, learning, and mastery of fundamental concepts.

Bibliography

Appendix 1
Problem Set Zero for CE364

Problem Set #0 (25 points)
Assigned Now!

Due at the start of Lesson 2

The purpose of Problem Set 0 is to review material you have already learned in CE300. Each concept presented you have seen before, and is necessary for you to review to be successful in this course. The problem set works as follows: You will continue to work on this requirement until you complete it correctly. Your first turn-in will be lesson #2. If there is an incomplete element to a problem type, you will rework it and work another problem provided by your instructor. This process will continue until you have demonstrated mastery of the problem types listed below.

1. (10) Equilibrium and Shear and Moment Diagrams.

   a. For the beam, as shown in Figure 1 below, calculate the unknown reactions at the left end of the cantilever beam.

   ![Figure 1](image)

   **Figure 1**

   b. Draw the shear & moment diagram for the beam. (Label all values on the diagrams in accordance with CE300 standards)

   c. Identify the location of maximum shear force and maximum internal bending moment along the length of the beam. Why are these locations important?

2. (5) Properties of Areas. The beam shown in Figure 1 has a cross section as shown in Figure 2 below.
a. Determine the composite centroid for the cross-section. Note: the CPO is located at the bottom center of the cross-section, as shown in Figure 2.

b. Calculate the composite moment of inertia (I) for the cross-section.

c. Calculate the first moment of outward area (Q) at point A, the web-flange interface near the top of the beam cross-section.

3. Fundamentals of Torsion (5). A solid circular shaft made of A36 structural steel has a torque applied to its free end, as shown in Figure 3 below:

If the diameter of the shaft is 60mm, calculate the shear stress due to torsion in the shaft and the deformation at the end of the shaft with respect to the fixed end.
4. Stress-Strain Curves (5).

a. Please label the following on the stress-strain curve provided below:

- Modulus of Elasticity
- Proportional Limit Stress
- Yield Stress and Yield Strain
- Elastic Region
- Plastic Region
- Yielding Region
- Strain Hardening Region
- Ultimate Stress and Strain
- Fracture Stress and Strain

b. What is the equation relating stress and strain in the elastic region?

c. What is the equation used to calculate the deformation in a centric axially loaded member in the elastic region.
Appendix 2
Problem Set Zero for CE483 & 404

Name: ________________________________                      6 MAY 09
Hour: ________________________________

CE403 FINAL (CE483/CE404 ENTRANCE) PROBLEM SET

Instructions:

1. In keeping with the idea that this is a 9.5 credit hour course, this problem set will serve as an entrance mechanism to ensure that you remember everything from CE403 that you will need in order to succeed in CE404 and CE483.

2. This problem set will count for 100 points in BOTH CE404 AND CE483.

3. You can use any references that you have available to complete this problem set. Some of the information may seem very similar to what we have done in CE403, so please refer back to your class notes, problem sets, and WPRs. Your MSC and ASCE 7-05 will also be extremely useful.

4. This problem set will be graded on a binary system meaning that either you get the correct answer or you do not. **If you do not get the correct answer, then you will get another opportunity to get it correct, but you will be docked the appropriate amount of points. You WILL continue to get this problem set back until it is 100% correct.**

5. Make sure to document all references and work that you did not complete. When in doubt use the parenthetical documentation.

---DO NOT WRITE BELOW THIS LINE---

<table>
<thead>
<tr>
<th>Problem</th>
<th>Points</th>
<th>Score</th>
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<tbody>
<tr>
<td>1: Short Answer</td>
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<td>2: V/M Diagram</td>
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<td>3: Loads</td>
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</table>
**Problem 1 (20 Points) Short Answer:**

a. What is the $1,000,000 equation? (Write in both variable format and in word format)

b. Which part of the $1,000,000 equation did CE403 prepare you to determine?

c. Which load case combinations should you consider when trying to determine the loads on a structure?

d. What is the general form of the virtual work equation if I wanted to find a displacement?
Problem 2 (20 Points) Shear and Moment Diagrams:

a. Draw the Shear and Moment Diagram for the beam below. Note that at the start of the distributed load, there is a hinge (no moment transfer).

b. What are the equations relating the applied load \( w \) to shear \( V \) and shear \( V \) to moment \( M \)? (Think Integrals)
Problem 3 (30 Points) Load Calculations:

1. What is the dead load (in psf) associated with the roof diagram below?

2. What is the snow load (in psf) for a building with a Category II importance located on Fort Leonard Wood, MO, in a fully exposed wooded area that prevails in the upwind direction?

3. Assume that the dead load on the structure below is 65 psf. First, use the symbols on the frame to identify the type of structural member (interior/exterior and beam/girder/column) and write it in to the right of the frame. Second, how would you model this load on the interior beams and on the exterior girders? Report answers in a format much like seen below Figure 1.
Problem 4 (30 Points) STAAD.Pro:

1. Model part of the frame in Figure 2 using STAAD.Pro by turning the 3D model into a 2D analysis along the x-x plane only. Use the area loads provided to calculate the dead load, live load, snow load and wind load that should be applied to the frame. Each of the girders has a beam framing into its end and at the center of its span, even the first floor in the two-story section.

**Material/Dimensional Properties:**
- Columns (A, B, C, D, E): Steel, $F_y = 50$ ksi, W8x21
- Girders (F, G, H): Steel, $F_y = 50$ ksi, W14x82
- Cross Bracing (I, J, K): Steel, $F_y = 50$ ksi, WT4x12

**Loading:**
- Dead Load: 60 psf
- Live Load: 25 psf
- Snow Load: 20 psf
- Wind Load: 20 k @ node 2 and 22 k @ node 5 (acting in the positive x-direction)

2. Create a STAAD.Pro report which contains a picture of the structure (include dimensions, supports, and beam/node numbers and material sizes), a picture of each service load condition (D, W, L, and S), Beam Maximum Axial Forces, Beam Maximum Moments, and Nodal Displacements for all load case combinations checked. Highlight the controlling load case combination for each member in each report. Which load case combination controls?

Assume: The cross members are tension only members, include the member self weight, and members H, F and G have simple connections to the columns (you need to release the ends). Use the labeling denoted in Figure 3! 
Figure 2: STAAD.Pro Analysis Frame

Figure 3: STAAD.Pro Frame Labeling (Members are marked with triangles and nodes are marked with squares)