Using Case Studies and Educational Technology to Teach Structural Analysis and Design to Construction Engineering and Management Undergraduates

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Abstract

During the Fall 2019 semester, 19 construction engineering and management undergraduate students were enrolled in one four-credit course that combined structural analysis and design, which has typically been taught as two separate courses for civil engineering students. To engage the students and increase subject mastery, case studies and MasteringEngineering™ are used. The main objective of this study is to examine relationships of student learning when analyzing and calculating design loads on structural members using the ASCE standard Minimum Design Loads and Associated Criteria for Buildings and Other Structures (ASCE/SEI 7-16). Students worked in groups of 3-4 during a 50-minute in-class design lab to determine the design load acting on structures, where many of the case studies consisted of structural failures due to excessive loads or under-designed members that may have resulted in structural collapse. Online interactive educational technology, which provided video tutorials, were also integrated into our learning management system (LMS) for supplemental instruction outside the classroom. In this study, the case studies appeared to help reinforce basic concepts for determining loads on structural members while also helping to motivate learning. Based on analytics from the LMS, students who viewed the course content more frequently earned either an A or B in the class, suggesting a link between increased student preparedness and performance.

Background

Several science and engineering educators are committed to using different methods and techniques to improve student learning and engagement [1-3]. To shift engineering education, multiple ways to present concepts can aid student understanding and learning in science and engineering. Using case studies to enhance civil engineering education is not a new concept [4-5]; rather, both the student and instructor can learn new insights through this process regarding strategies to improve learning and teaching. Case studies can be an effective way to teach or reiterate basic concepts through examples that can also appeal to different learning styles and provide a real-world context. MasteringEngineering™ was mainly used for the structural analysis portion of the class, where Hibbeler’s textbook on Structural Analysis, 10th edition was used to assign homework problems and provide real-time hints and feedback for the students while problem-solving outside of class.

Evidence and theories have shown that students need more exposure to real-world problems and design to improve their understanding [6] as a result of high-impact educational practices [7]. Researchers have also noted that the discovery of structural behavior and loading is just as important as learning the theories of structural analysis to prepare the next generation of engineers [8]. In this paper, case studies are used to provide contextual meaning and relevance to real-world situations to enrich the student learning experience and expose 19 construction engineering and management undergraduate students to structural analysis and design into one four-credit course.
The course, CIEG 396 *Structural Analysis and Design*, was established to meet the need for undergraduate construction engineering and management students to learn both structural analysis and design in one 4-credit course. Construction engineering and management (CEM) is a relatively new undergraduate degree program within our Department of Civil and Environmental Engineering, where the first cohort started in Fall 2017. The intent of a course is to provide CEM students with basic working knowledge on how to analyze and calculate design loads on structural members. A flowchart of the curriculum and how this course, CIEG 396, is sequenced within their curriculum is shown in Appendix A.

The class met three times per week: 50-minutes on Mondays for a design lab and then on Tuesdays and Thursdays for 75-minutes of lecture. There were two main challenges when developing this course, which was co-taught by the first two co-authors: 1) how to take content from two major courses and package that into one course, and 2) identifying the most important topics that students needed to learn for a level of proficiency in both structural analysis and design. To address the aforementioned challenges and assimilate massive amounts of information, the instructors decided to use case studies to help introduce basic concepts with the backdrop of real-world design scenarios during the 50-minute design lab. In addition to the design lab, MasteringEngineering™, which is an online teaching and learning platform designed by Pearson publishing company, was used for assignments and integrated into the learning management system (LMS) for the course. MasteringEngineering™ was also used to provide reinforcement outside the classroom given the video tutorials available. As such, the following topics were addressed during the lectures:

- Loads and Basic Structural Design Concepts
- Idealization and Tributary Loading
- Determinacy and Stability
- Application of Equations of Equilibrium
- Statically Determinate Trusses
- Analysis of Beams and Frames
- Computing Deflections Using Various Methods
- Design Methodologies and Material Properties
- Compression Members: Concrete and Steel Design
- Bending Members: Concrete and Steel Design

Students were assessed based on submitted assignments (e.g. MasteringEngineering™ homework and solutions from cases studies), two exams, and one comprehensive final exam. A question related to design load scenario was included in Exam I and the Final Exam to compare student understanding and improvement, if any. Table 1 details the grading weights of this course.
Table 1. Composition of CIEG 396, Fall 2019

<table>
<thead>
<tr>
<th>Components</th>
<th>Grading Weights</th>
<th>Lowest Grade Dropped</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Lab Assignments</td>
<td>10%</td>
<td>No</td>
</tr>
<tr>
<td>MasteringEngineering™ Assignments</td>
<td>10%</td>
<td>Yes</td>
</tr>
<tr>
<td>Exam I</td>
<td>25%</td>
<td>n/a</td>
</tr>
<tr>
<td>Exam II</td>
<td>25%</td>
<td>n/a</td>
</tr>
<tr>
<td>Comprehensive Final Exam</td>
<td>30%</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Methodology

The main objective of this study is to compare student learning of analyzing and designing structural members using per the ASCE standard Minimum Design Loads and Associated Criteria for Buildings and Other Structures (ASCE/SEI 7-16). Through the integration of practical case studies and MasteringEngineering™ assignments, it is hoped that students will gain a broader understanding of traditional analysis methods and how these methods are applied to solve real-world design challenges. Specifically, for the construction engineering and management students, the expected outcome is that the case studies in addition to the homework assignments with online assistance will provide students with a basic working knowledge and understanding of load path, stability and overall proficiency in structural analysis and concrete/steel design.

Seven (7) case studies were piloted for this class that focused on the topics in the bulleted list. Students worked in groups of three or four during a 50-minute in-class design lab to determine the design load acting on structures, where many of the case studies consisted of structural failures due to excessive loads or under-designed members that may have resulted in structural collapse. The case studies were ideal for the 50-minute design studio, which were an efficient way to organize group problem-solving and empower students to share their knowledge, idealize the structure, determine the load path as a part of the analysis process before calculating the design loads on the structure, and then designing the members based on the demand loads. The case studies were presented in the form of design modules (developed by the 2nd co-author) that students solved in groups to demonstrate their understanding of the relevant topics. Samples of the case studies are shown in Appendix B. The modules included exercises such as estimating the design loads present at the time of the Hartford Civic Center roof collapse to designing beams and columns for a small, two-story building. In addition to the case studies, students were assigned eight (8) homework assignments throughout the semester via MasteringEngineering™ that mirrored the lecture topics to reinforce understanding and learning.

Results and Analysis

To analyze student learning and effectiveness using the case studies, we looked at the student performance (i.e., grades) of all 19 students in the class based on four main categories: 1) assignments (i.e., 7 case studies and 8 homework assignments via MasteringEngineering™), 2) Exam I (structural analysis material), 3) Exam II (structural design content), and 4) comprehensive Final Exam.
To uncouple the topic of design loads, a problem regarding design loads was assessed during Exam 1 and then again in the comprehensive Final Exam. *Fig. 1* shows that 95% of the students either improved or earned the same grade out of 25 points when the concept was assessed during Exam I compared to the Final Exam. This suggests that students were able to grasp the concept of idealizing a structure and determine how to estimate the design loads on a structural member, possibly because of exposure and practice solving different problems via the case studies and homework assignments. While students showed a general understanding of design loads, we also wanted to look at the overall student performance based on other assessments.

![Design Load Problem Assessment](image)

*Figure 1: Design Load Student Assessment*

From student sampling, *Fig. 2* shows that most students were able to complete the assignments, that is the case studies and homework assignments, with an average of 92%. The average for Exam I and Exam II was roughly the same—84%, where Exam 1 focused on the material related to structural analysis with the 1st co-author as the instructor and Exam II focused on the design content administered by the 2nd co-author. However, students struggled the most during the comprehensive final exam, where the class average was a 69% and students were expected to pull all concepts together to demonstrate their understanding and learning of the material. From Fig. 2, the final grade percentage closely follows the trend of student performance from the assignments (i.e. case studies and homework), which was only 20% of the total weighted grade. Recall that the comprehensive Final Exam was worth 30% of the grade for the course.

Another interesting finding is the relationship between student engagement and student performance. One metric that was used to assess student engagement was based on the data analytics provided by our learning management system (LMS); that is, the number of times the student clicked on page views for the course using Canvas. The average of page clicks for the
The course was 470, shown by the solid black line in Fig. 3. **Fig 3** shows the number of page views (or clicks) per student with their final grade percentage stacked on top.

![Student Assessment of Learning](image)

**Figure 2: Overall student grades assessment for the course**

![LMS Page Views and Final Grade Percentage by Student](image)

**Figure 3: Insights on student engagement and performance from learning management system (LMS) page views**
With the exception of a few students, the majority of the students who exceeded 470 page clicks (i.e., student was engaged with the online course content), earned a grade of B or better. The final grade distribution for the class is displayed by the pie chart in Fig. 4, where 9 students (or 47% of the class) earned either an A or B, and the remainder of the class (53%) earned a grade of C. The authors will continue to analyze this data in more detail to find statistically significant correlations.

In addition to the quantitative analysis to understand the influence of case studies and online homework assignments on student learning and performance, a quantitative survey was administered via Survey Monkey to glean what the student thought about the use and effectiveness of the class studies and homework assignments. Nearly two-thirds of the students – 12 of 19 – responded to the (voluntary) survey. Fig. 5 revealed that 62% of the respondents generally agreed that the MasteringEngineering™ problems assigned did assist with their basic understanding of the structural analysis concepts. The responses received in the “other” category were quite insightful in that MasteringEngineering™ was used primarily for the structural analysis content given that the corresponding to a textbook where only analysis was taught. Students completed the design problems by hand so MasteringEngineering™ was not used for the design topics. Consequently, the students felt that access to this online software was a bit expensive to justify for only part of the course. From Fig. 6, it was reassuring to know that 100% of the survey respondents either strongly agreed or agreed that the case studies presented in the design lab did assist with their understanding and estimation of design loads using ASCE7-16, which was one of the main objectives of this course.

Q2 Do you feel the MasteringEngineering problems assigned assisted with your understanding of basic structural analysis concepts?

Figure 5: Survey question to assess effectiveness of using MasteringEngineering™ for homework assignments
Conclusions

A total of 19 construction engineering and management students enrolled in CIEG 396 (Structural Analysis and Design), which was taught as a combined course for the first time. To assist with covering a wide range of topics from analysis to design so that students can have a basic level of proficiency, case studies of real-world problems and online homework assignments were introduced. Given the large amount of material and range of topics, the aim of this study was to utilize the case studies and homework as an effective means to improve student understanding and learning while also motivating the topic for student interest. A few key findings from the study are summarized:

- Using case studies to motivate and provide an opportunity to apply basic concepts of design loads in a practical context helped to stimulate interest and understanding.
- Student performance and student survey feedback showed that utilizing case studies as an effective teaching strategy can enhance student learning.
- From the educational technology and learning management system, student engagement with technology revealed an interesting relationship between student engagement and performance; students who were more engaged in the class via page views and accessing the technology reported to perform better (on average) in the class.
- Moreover, students who performed better on the assignments (i.e. case study examples and MasteringEngineering™ homework assignments) tended to perform better in the class overall.
Additionally, a few key lessons learned regarding the integration of case studies into the course via a design lab revealed some noteworthy points:

- **Timing and Planning:** keeping on schedule with the lecture topics was critical in making sure that students had the information needed to understand how to solve the case studies.
- **Strategies for Effective Learning:** the case studies enabled students to apply concepts presented in lectures.
- **Combining Analysis and Design:** future work is underway to streamline the course and evaluate other programs that teach both analysis and design into one course. We will identify the most critical topics needed for teaching both analysis and design, match the topics with the more interesting case studies, and create new ones in some cases, to continue enhancing student understanding and learning of structural analysis and design. Future work also includes tracking student performance in subsequent and more advanced classes.
References
Appendix A: Curricular Flowchart for Construction Engineering and Management (CEM) Program
Appendix B: Two Samples of Case Studies

Problem 1

Hartford Civic Center Roof Collapse

The roof of the Hartford Civic Center located in Hartford, Connecticut collapsed in the early morning of January 18, 1978 after the area experienced the largest snowfall in the history of the five-year "old" structure. Fortunately, no one was injured in the collapse. However, the center had been filled just a few hours before the collapse with spectators for a basketball game. Immediately afterwards, an investigation was begun to determine the cause of the failure. A suggested potential cause of the failure was that the heavy snowfall exceeded the design load. Your task is to investigate this hypothesis.

Use the snow load handout provided under the Resources tab on the course Sakai website and the applicable load combinations for strength design to determine the required design total load for the roof of the structure.

Assume the following:

- The dead load on the roof was 20 pounds per square foot.
- The slope of the roof was less than 30 degrees and the surface of the roof can be classified as "all other" for the purposes of finding Cs.
- $C_a = 1$

Problem 2

A three-story hotel (that is two floors and a roof, no basement) has interior columns that are spaced 20 feet apart in two perpendicular directions. If the roof design dead load is 25 pounds per square foot, the floor dead load is 75 pounds per square foot, and the roof design snow load is 35 pounds per square foot, determine the total axial load (using strength load combinations) supported by a typical interior column at (a) the ground level, and (b) a point located slightly above the second floor level. Do not consider live load reduction.