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Horizontal Integration of the Same Design Project in Multiple Structural Engineering Courses

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Abstract

The effective use of design projects in engineering classes or capstone style courses has been well documented. Design projects introduced in a single course can help connect esoteric concepts, reinforce team-building principles, and bring practical considerations into the classroom. However, many of the concepts taught and learned in these courses may be left behind when the student moves on to another design course or focus area within civil engineering. Capstone style courses are frequently used to instill the importance of the overall design process, but this may not be completed until the final semester or year of study. The global objective of this research study was to horizontally integrate the same design project in multiple structural design courses to incorporate the concepts of iterative design, design options, and continuity among structural engineering classes (e.g., reinforced concrete, steel, prestressed concrete, etc.).

The approach of horizontal project integration may better represent the concept of design-build, which is a common project delivery technique in the structural engineering industry. The design and construction engineers work together as a team to efficiently design and build a project. The process often includes working on the design while construction is underway; design iterations and changes are inevitable as the project progresses. To simulate a design-build project, a real world design project was introduced into both steel and reinforced concrete design classes at multiple universities.

There were several goals to achieve using this form of instruction. The first goal was to determine if the same project could be adapted in each course, such that students complete the same design with two different materials. The second goal was to expose students to different structural details within the same set of overall building plans (i.e., the details and requirements for concrete and steel vary) while bolstering their ability to read and interpret drawings used in the industry. The final goal was to assess if students connected topics from previous classes (e.g., structural analysis and statics) to the current design classes and if the project helped them retain knowledge.

The project has been implemented in reinforced concrete and steel design courses. The basic design process for each class included tracing the load paths and using the applicable code to design a typical set of beams, girders, and columns. An initial survey was used to assess the student's ability to perform structural analysis and interpret construction drawings. A final survey assessed the gains made within each class (i.e., design of reinforced concrete and steel) and the gains made in material related to ancillary topics. Furthermore, comparisons were made between the initial and final project submittals in the different classes and between feedback recorded by the instructors of each class. The results indicate that horizontal integration is possible within a structural engineering curriculum and may lead to better global understanding and retention of the material, but implementation requires careful coordination and forethought because of the idiosyncrasies between the design courses.

Introduction

Civil engineering has a distinct set of engineering concepts that should be learned at the bachelorette level in order to create the knowledge base required to be a practicing professional engineer[1]. Having students retain what they learn while also preparing them for real world experiences is a challenge for educators. Traditionally, topics are taught in separate classes (i.e., foundations, water resources, reinforced concrete, etc.) although subjects overlap in the engineering industry. Furthermore, there has been pressure by many state governments to reduce the number of credit hours to obtain a bachelor's degree[2,3]. To overcome these challenges, educators must be creative and implement multiple topics and techniques into a single course. This is especially true when trying to teach non-technical engineering skills such as professionalism, communication, and economics as articulated in the ASCE Body of Knowledge[4]. Activities such as design projects, field trips, and laboratory experiments are often used to help provide a well-rounded education.

The objective of this research was to explore the design-build process in a series of horizontal design courses. Design-build is a common project delivery technique in the structural engineering industry. Designers and contractors work as a single entity to design and build a project simultaneously. The beginning of the process often includes iterations and changes as the project progresses. Design-build project delivery, through a single contract with the owner, transforms the designer and builder relationship into an alliance, which fosters collaboration and teamwork[5]. To simulate this project delivery technique, the same design project was implemented in two horizontal structural design courses. The preliminary design of the structure had already been completed by an industry partner with a different structural engineering material, but the students were asked to complete an alternative design with the material taught in their course. Experiencing the interrelationship among similar subjects while in school is a very useful exercise for students. Abbott and Penney[6] stated that "students who enter the workforce having been exposed to broader and more collaborative curricula will be far better equipped to handle the myriad [of] challenges they will face [in the architecture, engineering, and construction profession], regardless of their chosen discipline." Ideally, this project benefited students by connecting the design process to the concept of both iterative design and design options.

Background and Goals

The effectiveness of design projects in design or capstone style courses has been well documented[7,8,9]. The inherent nature of projects that are open-ended and have many correct solutions requires students to implement several topics from class simultaneously. Additionally, collaborative team activities can also be incorporated to make the projects more realistic and require the students to use knowledge on topics from non-engineering courses such as verbal and written communication skills. Most capstone style classes and projects are implemented during the final year or even semester of study. However, some universities have used projects within a single design class instead of requiring a separate capstone experience (e.g., University of California-Berkeley[10], Cornell University[11], North Carolina State University[12], and Virginia Tech[13]). Regardless of the timing or implementation method within the degree program, teamwork, communication skills, and review of engineering topics are routinely referenced as valuable objectives of these projects. Students are required to combine topics from multiple classes, work together, and produce a final professional product. These courses may provide the only opportunity for students to implement all of their professional skills at the culmination of their degree.

Architectural, engineering, and construction professionals work together on large collaborative projects through the design-build process in today's fast paced business environment; there are many companies who specialize in this specific type of construction procedure (e.g., Bechtel, Flour Corp., Kiewit Corp., or Whiting-Turner Contracting)[14,15]. A capstone style course could be used to implement design-build concepts (e.g., design iterations, consideration of alternative designs/materials, and flexibility in the final product), but there are some drawbacks to this method of implementation. First, capstone courses may serve to focus on the communication, business, and team building skills as much as or more than the technical engineering side of the project. Many projects are very broad and must be accomplished within a semester, which results in less depth on the technical side of the project. Second, it is time consuming and challenging to review previous topics, complete technical designs, and implement the team-based project simultaneously in one class. Third, many students split up work during team projects and may not gain experience in every technical aspect (i.e., structural design, foundation design, transportation planning, etc.). Finally, capstone style courses are implemented toward the end of the education process; ideal timing for experiencing the design process is in the design classes.

To overcome some of these drawbacks, the same design project was horizontally integrated into a reinforced concrete design course and a steel design course. Reinforced concrete and steel design courses are two of the fundamental classes in a structural engineering curriculum. At many universities, these courses are traditionally taken by students during a junior or senior year of study. They are unique courses that do not depend on one another, but they have similar learning outcomes based upon different engineered materials and they require the same prerequisite courses. Steel and reinforced concrete design classes are frequently taught separately because, while the topics are similar, the design codes and material behaviors are different. When using traditional instruction methods, the students come away understanding the nature of designing with the unique material, but they fail to recognize similarities in the overall design decisions and methods.

The design project in this research was presented as a design-build venture that was currently underway (i.e., the column grid layout had been established and the construction team had already started construction of the foundations), but a separate design option was desired. There were several goals to achieve using this form of horizontal instruction. The first goal was to determine if the same project could be adapted in each course, such that students complete the same design with two different engineered materials. The second goal was to continually expose students to different structural details within the same set of overall building plans (i.e., the structural detailing requirements for concrete and steel differ) while bolstering their ability to read and interpret drawings from the industry. The final goal was to assess if students connected topics from previous classes (e.g., structural analysis and statics) to the current design classes and if the project helped them retain knowledge.

Design-Build Project and Survey

The study was implemented in tandem at two different universities (denoted Univ 1 and Univ 2 in the data comparison tables). University 1 is a small, public, undergraduate only baccalaureate university with an art and sciences focus in a rural area of the Mid-Atlantic region. University 2 is a midsized, public, master's university in a medium density city in the West North Central Region. The same semester-long project was assigned in a steel design class at university 1 and a reinforced concrete design course at university 2. The background of the students was similar at both schools; the students had completed statics, mechanics of materials, and structural analysis courses. Most students at university 1 had already completed a reinforced concrete design course while students at university 2 had no previous structural engineering design courses. The students at university 1 were all seniors and were part of a class with either 14 or 18 students (32 total students). The students at university 2 were mainly seniors and were part of a single class of 20 students. The undergraduate students at both universities were not required to take the respective course as part of the civil engineering curriculum (regardless of interest or concentration area).

The horizontally integrated project focused on a parking garage previously designed and built as a prestressed concrete structure. The design project was submitted in three phases over the course of the semester and the technical content of each submission aligned with the content presented in class. The design project was introduced during the second week of the course and continued until the final project was submitted on the last day of instruction. Aside from grades, students also received comments on the first two submittals regarding issues that needed to be addressed. These comments ranged from incorrectly completing technical calculations to a lack of professionalism in their submitted report. Students were encouraged to fix outstanding issues prior to the next submittal and make note of their changes with a memo. The reward for improving the project was a higher final grade. Only items communicated through the memo were reviewed during assessment, regardless of what may have been improved within the project. This resubmittal method put the burden on the students to thoroughly document and communicate any changes and improvements.

The project required students to review fundamental concepts from the prerequisite class (structural analysis), consider constructability issues when they designed members that connect, and use engineering judgement when selecting the most economic and constructible design. The set of plans given to the students (obtained from an industry partner) included the parking garage geometry, material properties, and the original prestressed concrete design. Students were told that the client/owner wanted to change the structural design and that a reinforced concrete or steel option was desired. They were required to fulfill their clients request by completing a separate design iteration using their respective material. However, to simulate design-build projects, the building foundation was already placed and the client wanted to retain the same column layout, overall parking garage geometry, and material properties.

The students were required to gather all of the design information from the set of existing plans. This included the loading on the structure, the material design strength for each individual component (e.g., concrete slab, beams, columns), and the layout/elevation dimensions. Students investigated the differences between interior and exterior members and were required to complete the tasks listed in Table 1 to finalize their design. Individual project submissions included three main components: (1) professional cover sheets, summary memos, and a table of contents with numbered pages, (2) design calculations completed in the computer program Mathcad, and (3) an accompanying set of stand-alone construction drawings created in AutoCAD that included a plan view, appropriate section cuts, and appropriate elevation views.

Table 1 – Design tasks for each class

Design Task	Reinforced Concrete	Steel
Tributary widths and area	X	X
Unfactored and factored loads	X	X
Shear and moment diagrams	X	X
Beam deflection		X
Flexural beam design	X	X
Shear beam design	X	X
One-way slab design	X	
Column design	X	X
Base plate design		X

A survey was also developed for use with this design project. The survey was given to the students at the end of the first week of the semester prior to assigning the project and during the final week of the semester when the final design project was submitted. Completion of the surveys was optional. All responses were provided anonymously and participation was not graded. Four questions were asked in both the initial and final survey:

1) With my current knowledge, I can find a column layout on a set of engineering plans.
2) With my current knowledge, I can find beams and girders on a set of engineering plans.
3) With my current knowledge, I can find material properties and general notes on a set of engineering plans.
4) With my current knowledge, I can trace a load path in a structure.

Three additional questions were asked in the final survey:

5) With my current knowledge, I also feel comfortable finding the following items in a set of structural engineering plans (provide a list).
6) With my current knowledge, I am more prepared for a senior design class.
7) Did the design project help connect ideas you learned in other classes to topics from this class?

The goal of the first three questions was to assess what information students brought into the class. Specifically, the questions were used to determine if students could adequately identify structural components (e.g., beams and columns) and assess their ability to read construction documents. The goal of the fourth question was to assess student retention of load path concepts from their previous structural analysis class. Questions 5 through 7 asked students to evaluate their perceived gains in areas related to concrete or steel design and in areas not directly related to the class. Answers to Questions 1 through 4 were limited to the following: Not at All, Just a Little, Somewhat, A Lot, or A Great Deal. Question 5 was an open-ended question. Results from the final survey were compiled and compared to the initial survey responses. Observations from the surveys were compared to the general trends observed within the design project and on homework assignments in the class.

Results

The results from horizontal implementation of the same project in a reinforced concrete design course and a steel design course at two different universities are presented. The students' perception via surveys and course evaluations, the project results, and lessons learned are explored.

Student Surveys and Evaluations

The initial survey was given to the students at the beginning of the semester, prior to assigning the project, to establish their perception of their abilities. University 1 had 17 of 32 students respond to the initial survey and university 2 had 17 of 20 students respond to the initial survey. The final survey, which contained the same questions as the initial survey along with three additional questions, was administered to the students following completion of their project during the last week of the semester. University 1 had 22 of 32 students respond to the final survey and university 2 had 19 of 20 students respond to the final survey. In both cases, the surveys were optional, anonymous, and not tied to a grade, which likely contributed to participation rates less than 100%.

Questions 1 through 3 involved reading plans and understanding basic structural engineering. Question 1 asked the students if they could find a column layout on a set of plans. The most common initial survey response for university 1 was "Somewhat," which indicated average ability. However, no one responded "Not At All," which would have indicated that the task could not be completed. At university 2, the initial survey responses were nearly even between the lowest four categories, which indicated that students had mixed levels of plan reading abilities and few students felt overly confident in their ability. Initial survey responses for Question 1 are shown in Figure 1. Differences between the two university's initial survey results were logical considering the students' background. At university 1, every student held senior standing, most had already taken reinforced concrete design, and most had already taken an introductory project management course that covered plan reading. In addition, several students had held internships in the construction industry the previous summer. At university 2, the majority of the students held senior standing but had not taken a structural design course and had not been formally exposed to plan reading.

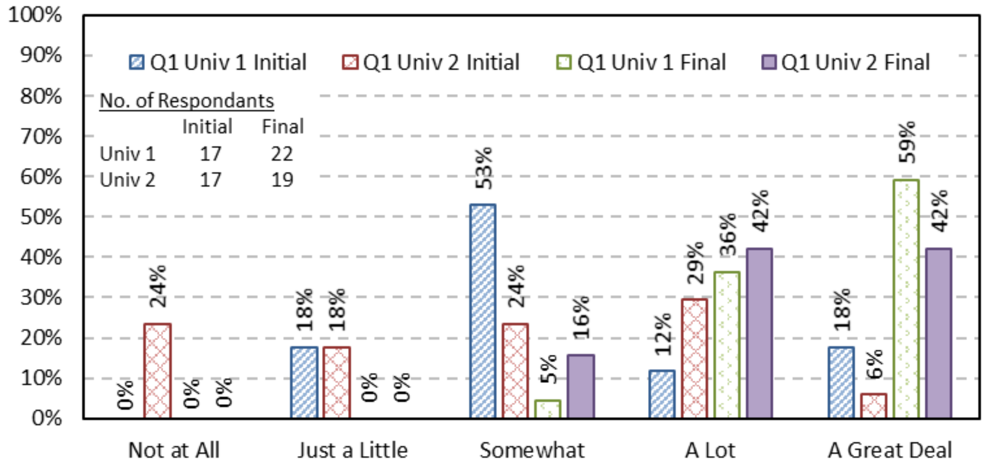

Figure 1 – Comparison of the initial and final survey responses for Question 1

Question 2 asked the students if they could find beams and girders on a set of plans. Approximately two thirds of the initial survey responses at university 1 were "Somewhat," which indicated average ability. Similar to Question 1, no one responded "Not At All," which would have indicated that the task could not be completed. At university 2, the initial survey responses primarily indicated average ability ("A Lot" or "Somewhat"). Initial survey responses for Question 2 are shown in Figure 2. The pattern of initial survey responses for Question 2 were similar to Question 1; students with a stronger structural engineering background felt more comfortable completing the task. Considering both questions asked about a similar skill, the results and differences between universities were logical.

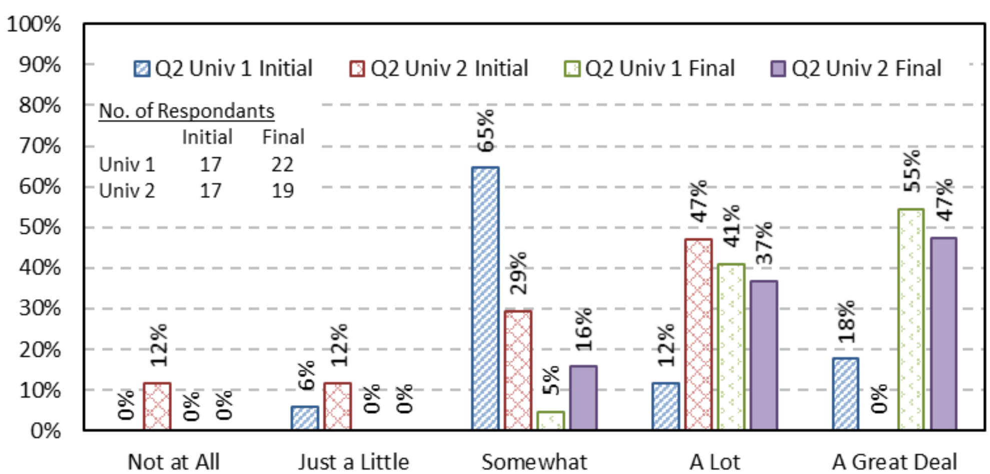

Figure 2 – Comparison of the initial and final survey responses for Question 1

Question 3 asked if students could find general notes and material properties on the plans. The initial survey responses at university 1 formed a bell curve centered at the average ability response "Somewhat." The students at university 2 had more confidence and responded "A Lot" and "Somewhat" most frequently on the initial survey. These students felt they had a better understanding of this part of the plans, a slight increase in their perceived ability compared to identifying columns, beams, or girders on structural plans. Initial survey responses for Question 3 are shown in Figure 3.

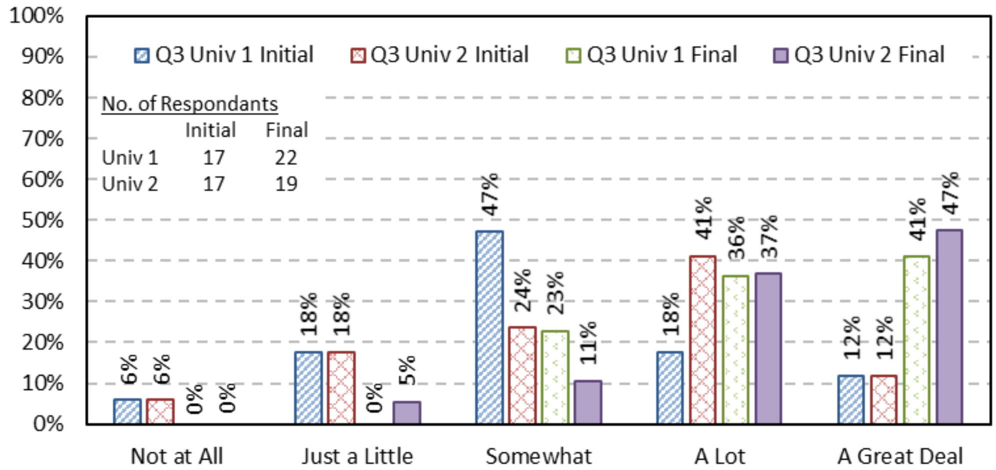

Figure 3 – Comparison of the initial and final survey responses for Question 3

The students at university 1 and university 2 showed a growing confidence in finding items on structural plans in the final survey. Final survey responses for Questions 1 through 3 were most often “A Great Deal” or “A Lot,” which indicated a high confidence in reading plans and understanding basic structural engineering. Very few students responded “Not At All” or “Just a Little” on Questions 1 through 3, which would have indicated that the task could not be completed. Final survey responses for Questions 1 through 3 are shown in Figure 1, Figure 2, and Figure 3, respectively. The students at university 1 had slightly more confidence on the first two questions but slightly less on Question 3 when compared to students at university 2. All of the students at university 1 had completed a course on construction documents, so this steel design class appears to have helped them review the topic and gain more confidence. Very few of the students at university 2 had a previous structural design course, so this reinforced concrete design class adequately introduced the topic and gave them confidence. Overall, the final patterns were similar at both schools and the students seemed to make gains in their confidence related to reading structural plans.

The fourth question asked the students “With my current knowledge, I can trace a load path in a structure.” This question was posed to the students at university 1 in both the initial and final surveys. University 1 student responses in the initial survey were typically “Somewhat” or “A Lot,” which indicates an average comfort level. Final survey responses at university 1 were typically “A Lot” or “A Great Deal” and demonstrated that most students felt they had a better understanding of load paths. At university 2, the question was only asked in the final survey with very similar results compared to university 1. Initial and final survey responses for Question 4 are shown in Figure 4. Load paths is not a major topic in these design courses, therefore the majority of the gains can be attributed to the use of load paths in the project. The students had covered this topic extensively in the prerequisite structural analysis course.

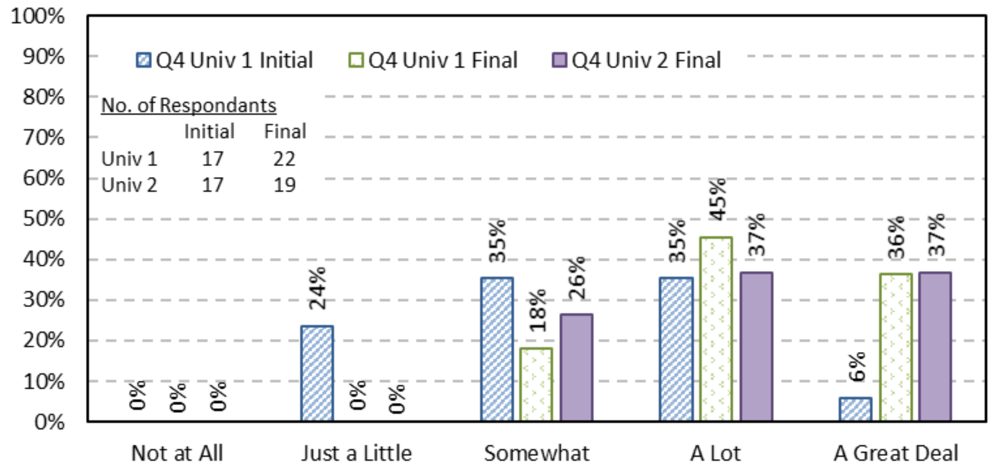

Figure 4 – Comparison of the initial and final survey responses for Question 4

The last three questions were asked in the final survey, after completion of the project. The fifth question was "With my current knowledge, I also feel comfortable finding the following items in a set of structural engineering plans (provide a list)." Due to the open-ended nature of the question, the results varied among students. The responses were categorized and compiled in Figure 5. The students at university 1 did not provide the depth of responses obtained at university 2. The three most common response categories were general notes, plan/elevation views, and cross sections. These are basic items on plans. The fourth most common response, applied loads, is directly connected to structural design. The focus on the general categories may have been tied to the required set of stand-alone construction drawings produced by students for the final project submittal. Regardless, the results show that students felt this class helped them review plan-reading topics that were related to, but not taught in, the structural design courses.

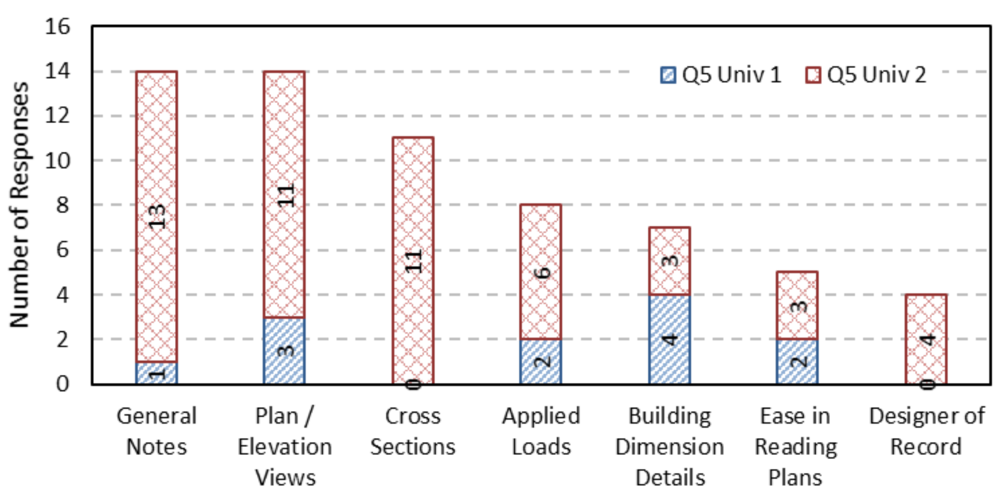

Figure 5 – Categorical count of the final survey responses for Question 5

The sixth question was "With my current knowledge, I am more prepared for a senior design class." Near the end of the semester, every student at university 1 had preregistered for the capstone course and had a basic understanding of what the course required. Of the final survey responses received, no one felt they were less prepared for the senior design course. At university 1, over 92% of the students felt the course helped them prepare extensively (more than an average review) while only 8% felt it only marginally helped them. At university 2, over 84% of the student responses indicated the course helped prepare them for the senior design course "A Lot" or "A Great Deal," indicating a better than average review. Approximately 15% of students felt the class "Somewhat" helped them prepare (an average review).

Question 7 on the final survey asked "Did the design project help connect ideas you learned in other classes to topics from this class?" At university 1, this was posed as an open-ended essay question. University 1 students who completed the survey unanimously felt this project helped them connect ideas from other classes. There were many write-in comments at university 1 noting that the project helped connect ideas from other structural analysis and design courses and helped them prepare for the Fundamentals of Engineering (FE) exam. Almost all of the students at university 1 took the FE exam during the same semester as this course, which likely contributed to the FE exam comments. At university 2, over 50% of final survey respondents felt the project helped them connect ideas from other classes, while 42% thought the project "Somewhat" helped them, and only 5% felt it helped "Just a Little." Overall, the students who responded to the survey felt the project added value by connecting engineering ideas from multiple classes.

The end of the semester anonymous course evaluations provided an additional layer of feedback on the project that was not originally anticipated. While this was an indirect and subjective measurement of the project effectiveness, the unsolicited comments provided valuable feedback. There was a 53% participation rate at university 1 (out-of-class electronic evaluations) and a 95% participation rate at university 2 (in-class paper evaluations). At university 1, there was a set of open-ended, short answer questions that asked "What course activity provided the most intellectual stimulation? Which was the least stimulating? Explain Why." Feedback was not requested concerning the project; however, 8 of 17 students who completed the evaluation mentioned the project. Each comment was positive and included statements such as "The project was a lot better than I thought it was going to be," "The project was interesting," "…made us apply it [material] practically," and the "Projects helped a lot in my understanding." Unexpectedly, there were no complaints about the project in reference to the length, time commitment, or complexity, even though the project required additional work in the class. At university 2, there were open-ended, short answer student evaluation questions that asked "What does your instructor do especially well? What could the instructor do to improve his/her teaching?" Feedback was not requested concerning the project; however, 7 of 19 students who filled out the evaluation mentioned the project. Positive feedback resembled "I really enjoyed the project and how it combined everything we learned" or "Thought the project was good and comprehensive." Negative feedback resembled "The final project took a lot of time along with the homework" or "Project was a little long, partners would have made it better."

Project Results

Students successfully completed the same basic building design in both classes using different engineering materials. The project was completed with multiple submissions, culminating in a final design presented as a professional report. Each submission was graded for technical competence, organization, and professionalism. The initial submissions were returned to the students to allow for corrections on subsequent submittals and on the final submittal. A similar grading rubric was used at both universities, so the feedback on various components was uniform. Throughout the semester, the design project process was documented to determine any particular aspects that went well and parts that needed improvement. The review was conducted both formally through the previously mentioned surveys and informally through discussions with students in and out of class.

The initial submissions included a large range of quality and organization. Typically, students spent the majority of their time on the technical content and did not save time to create a professional appearance. Part of this was because they knew they could resubmit the project based on their corrections. Organization and professionalism, while very important, were not the focus of the class and were inherently learned over the course of the project. Most students at university 1 had limited experience putting together professional documents, had not taken a technical writing course, and had not organized calculations in a computer program such as Mathcad. The project provided a means to identify knowledge gaps in their education, but it also helped them learn and practice technical writing skills by requiring multiple submissions. Students at university 2 had completed a civil engineering materials course that required many written laboratory reports and may have been enrolled in, or previously completed, a technical writing course required by the curriculum.

The initial submission covered topics that would have been previously completed by engineers during the first iteration in a design-build project. The material properties and loads had already been provided on the plans to simulate the design-build concept. The provided plans listed the American Institute of Steel Construction (AISC) and American Concrete Institute (ACI) design codes that were used by the industry designers and students in class. The plans also listed explicit material types for reinforcing bars, concrete strength, and steel grade. The students were required to reference these materials and look up the mechanical properties in relevant resources such as ASTM manuals, textbooks, or online resources. Plan references to the appropriate concrete (ACI 318) and steel (AISC Manual of Construction) design manuals reinforced their importance to students and helped connect the class to the project. In essence, by giving the students a design that was already complete, they were able to see what their final submittal should include and how a professional engineer would assemble their final design-build construction documents. Class discussions and project feedback over the semester kept the students focused on the design-build process simulated in their project.

Part of the initial project submission required students to layout tributary areas, factor loads, and draw shear and moment diagrams. These concepts were all learning objectives from the prerequisite structural analysis course, but they were also briefly reviewed at the beginning of the semester in the design courses. Most students were able to find tributary areas, identify the type of loads, and draw shear and moment diagrams. Approximately a third of students at both universities incorrectly factored loads to Load and Resistance Factor Design (LRFD) strength levels; common difficulties included determining whether to factor design loads before or after finding design shear and moment values and mixing load factor equations when designing members that carry loads from various parts of the building. Students also encountered difficulties with constructing shear and moment diagrams for girders that contained point loads from adjacent beam framing or wheel loads. Finally, a lack of exposure to Mathcad software created an initial learning curve that required more time; however, by the end of the design project students appreciated the software for its ability to remove repetitive hand calculations from the project. Students at university 1 did not have a programming class, therefore asking students to document their work in a computer program served as an excellent computer applications training tool. This highlighted the fact that the design project served as a way to connect all of the topics learned in class and as a secondary learning tool to reinforce skills such as written communication, organization, and professionalism.

Subsequent project submissions included an opportunity for students to correct mistakes and improve their overall project layout and appearance. In these submissions, students had to complete design tasks that had recently been covered in class and in homework assignments. Structural loads was a topic that many students struggled with on their submissions in both classes. After the first submission, the professors noted the increased number of questions on factored loads and load paths. Students understood the general concept of load factoring on a simple structure (e.g., one beam). However, they did not know how to apply the concepts to a real structure with multiple members and load paths. The precise method and timing within the design process for factoring was unclear. This was an example of a topic that builds in complexity from its initial introduction in a structural analysis class to its full implementation in a realistic design project. The students gained knowledge by applying a concept to the project that seemed simple in a previous class, but in reality was more complicated. This created valuable classroom discussions that led to significant improvements in the comprehension of how structural loads and load factors affect structural design.

A review of the subsequent submissions indicated that students took advantage of the opportunity to improve their Mathcad design spreadsheets, AutoCAD drawings, and the professional appearance of the project. Mathcad spreadsheets were often modified to include more clarity with documentation in the calculations, which benefits the students during future personal applications. Improvements to AutoCAD drawings included detailed dimensioning, section cutting on plan views to reference cross sections and elevations, and clarity related to where information should be located (e.g., provide dimensions on plans views and limit dimensioning in cross sections).

Final project submissions from the steel and reinforced concrete design courses included the same problem statement, applied loads (excluding self-weight), load factors, and load paths. Furthermore, the majority of the technical content in final project submissions was similar, but the order of the design process using the two materials was different. For example, the behavior of columns is typically covered first in steel design courses and last in concrete design courses. There were a few minor deviations between the projects as noted in Table 1, and these details were carefully considered at the onset in order to coordinate similar final project submissions. For instance, the parking deck slab was designed in concrete class while the column bearing plates were designed in steel class.

Approximately one third of the final submission grade was based on organization, professional appearance, and technical writing. The ability to correct previous submittals helped motivated students because they could improve their grade based on the extensive feedback. Based on the significant improvement in the final project grades, over 80% of the students benefitted from the opportunity to resubmit project corrections. The grade was a large enough incentive for most students to work hard on the final submission. Interestingly, those who turned in quality calculations at the end of the project also turned in a professional final submission. The students who lacked a final professional report were the same 15% that submitted insufficient corrections and had the lowest overall grades throughout the project. By the end of the project, the vast majority of students had a professional looking design project to present to prospective employers and software from their project for personal use. The iterative nature of this engineering design project, which included multiple submissions and the ability to fix mistakes, kept the students motivated and worked well as a learning tool.

Lessons Learned

There were additional lessons learned over the course of the design project that should be taken into account in future applications of this design-build process. Similar to most engineering courses, unmotivated students who turned in poor quality initial submissions often did not fix their mistakes and continued a lack of engagement in the project. The design-build concept required students to study the previous design, material properties, and layout prior to beginning the design process. Increasing the weight of the project in relation to the final grade, giving more assessment on how this project fits into the design-build process, or requiring resubmissions may help motivate student who were not engaged.

Student course evaluations also noted that, at times, the project submissions seemed to duplicate their homework assignments. While this allows students to practice their technical skills multiple times, it also may add more repetitive work to the course load. Future classes may be streamlined if homework and project assignments were intuitively meshed together or if students worked in pairs to complete the project. However, it is critical that the students are able to differentiate between routine practice problems and the difficulties affiliated with a professional design project. The project alone may not provide enough feedback and repetition for students to learn the fundamental design concepts.

The professors also learned that the guidance and feedback presented to students could be improved. Assessment of student work on the project required considerable time and effort from the professor due to the open-ended nature of the project and the fact that each student could have a different final design. This was particularly true for the concrete course. Iterative steel design, especially at the introductory level, is often considered easier due to the lack of variability in hot-rolled steel shapes and the large number of published design tables in the AISC design manual (i.e., select a member size based on a certain level of load). In concrete design, the engineer has several variables to select, which includes the members dimensions and amount/size of reinforcing. A lack of practical dimensional limits on concrete members led to students designing beams that had impractical geometry, but relatively simple designs. A similar problem was observed in the steel design course. The students checked deflections last in the design process and picked shallow girders that resulted in impractical deflections. More guidance on concrete constructability and limits on geometry in both classes may make the final project submissions more uniform, align with industry standards, and make the project easier to grade.

The design-build process was emphasized from the material and design perspectives, but the project economics were not considered. In reality, the economics of the project will drive the process and become an important consideration in final selection. In future applications of this design-build project, the students should be asked to compute a cost estimate or a simple quantity estimate of the materials needed for each design. The student's cost estimate could be compared to the original prestressed concrete design to simulate a more realistic process.

Conclusions and Ongoing Work

The same semester-long design project was horizontally integrated in both a reinforced concrete design course and a steel design course at two different universities to simulate the design-build process. Responses from initial and final surveys revealed students' perceived gains related to their structural design abilities. Project submittals, professor evaluations, and improvements made through the submittal process provided additional evidence when assessing the three goals of the project.

Reviewing the first goal of implementing the same project in two different structural design courses, the professors concluded that the basic building design and corresponding design principles could be completed using different materials. Each student essentially completed a preliminary design, which was similar to what a design firm may complete prior to selecting a final design; these designs served as an alternate to the original prestressed concrete parking garage design. These preliminary designs could be explored in detail in a subsequent capstone course. This would allow the capstone course to focus less on the technical content (already completed) and more on the "soft" engineering skills such as teamwork, communication, and evaluation of design feasibility and economics.

The second goal of exposing students to reading structural plans and details was accomplished by using the design-build project model. Students were presented an example preliminary design, but they were also expected to create a new set of drawings for their alternate design. While their initial submissions and drawings needed revisions, the repeat submission process resulted in over 80% of the class significantly improving their submission quality. The final survey responses confirmed that students perceived improvement in their abilities to read plans and connect structural analysis topics to structural design classes.

The final goal of connecting previous topics to the design course appears to be possible. After completing this project prior to capstone, it was perceived that the students would be more efficient and effective on their final capstone project. Many practical lessons were learned over the course of this design project that would benefit a future project, including impractical beam sizes and shapes, selecting beams with reasonable deflections, and implementing a cost comparison between designs with different materials. Project submissions and student feedback revealed that additional student guidance and adjustment of the course homework might be required to maintain a reasonable workload for the students and professors, especially in the reinforced concrete course.

The project is currently assigned and under investigation in three additional structural design courses to obtain more data for comparison to these initial conclusions. In particular, the researchers are interested to see if similar results occur when each professor, at different universities, teaches the opposite course. Furthermore, the same projects will be provided to a set of students in a longitudinal design course. At university 1, the project is currently being implemented in a sequential reinforced concrete design class. The hypothesis is that students will gain a deeper understanding of the structural design process and recognize similarities between design codes for different materials if they complete the process a second time. Observed student shortcomings included the inability to connect structural analysis techniques to a real design project. Horizontal and longitudinal implementation will assess if completing the project in multiple courses helps reinforce the integrated and collaborative nature of the architecture, engineering, and construction design-build industry. Alternatively, performing the project two times may be too redundant and not result in significant gains during the second design process compared to the amount of work expended. Preliminary data will be forthcoming in the spring of 2017 on the first set of students to perform the project in both a reinforced concrete and steel design class.

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