2018 ASEE Annual Conference & Exposition
June 24–27, 2018
Salt Palace Convention Center
Salt Lake City, UT

Paper ID #22123

A Case Study of Interdisciplinary Capstone Engineering Design

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Introduction and Objectives

The importance of interdisciplinary design experiences in engineering education is highlighted in the ASCE Body of Knowledge[1] and the ABET Engineering Accreditation Commission[2,3]. Professional competencies such as leadership, the ability to design sustainable systems, effective communication, and interdisciplinary teamwork are among the many skills required by engineers of the future. Functioning effectively as a member of a multidisciplinary team is a requirement for entry into the practice of civil engineering at the professional level. It also states that intradisciplinary and multidisciplinary teams are needed to solve the complex problems of the future[1]

The recently revised ABET student outcomes (1 through 7) no longer have an explicit outcome about functioning on multidisciplinary teams; however, it is implicitly stated that it is still important. Outcome (1) of the new ABET student outcomes state that students have "an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics". ABET then goes on to define complex engineering problems as those "…involving diverse groups of stakeholders, including many component parts or sub-problems, involving multiple disciplines, or having significant consequences in a range of contexts." Additionally, outcome (5) of the new ABET student outcomes state that students have "an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives".

One strategy for meeting the ASCE Body of Knowledge (BOK) and ABET requirements is through multidisciplinary senior capstone design experiences. The ASCE BOK (2008) defines a multidisciplinary team as being "composed of members from different professions —for example, a civil engineer working with an economist. Multidisciplinary also includes a team consisting of members from different engineering subdisciplines (sometimes referred to as a crossdisciplinary team)." It appears as though at many schools, traditional design problems in civil and environmental engineering have only a limited interdisciplinary aspect. These programs have addressed the ABET multidisciplinary team requirement by engaging students in crossdisciplinary design focused on the subdisciplines of civil engineering, including environmental, structural, geotechnical, transportation and water resources. Although this satisfies the ABET requirements, it does not truly engage students in an interdisciplinary experience and require them to work with students whose discipline-based knowledge is different from their own.

To this end, there have not been many documented examples of multidisciplinary senior capstone/design that includes environmental engineering or civil engineering students with students from other disciplines. Basha and Lee[4] describe a multidisciplinary project between civil and electrical engineering students focused on structural health monitoring, however the responsibilities of each group of students are not well-described, stating only that the nature of the teams were such that each student needed to provide specific skills in order to complete the project. After completion of the course, the authors noted that a key concern was that the civil engineering students did not participate as much as the students from the other disciplines.

Another potential issue with multidisciplinary capstone design involving civil and environmental engineers is the scale of the infrastructure design projects that are common in these disciplines. Frank et al.[5] described a multidisciplinary capstone senior design project program at Florida State University. Their multidisciplinary program includes mechanical, electrical and computer, and industrial and manufacturing engineering. The authors report that the program does not typically include civil engineering students, stating "….traditional design problems in civil engineering have only a limited interdisciplinary aspect". However, through an externally-funded grant, the program was able to include a wind turbine design project. The authors note that due to funding constraints, they were not able to actually build a full scale wind turbine and instead built a scale model. This reinforces a common issue for civil and environmental engineering programs, as many of the design problems and infrastructure components are large.

Dettman and Collett[6] from Western Kentucky University describe a civil engineering capstone design project that occurred during the 2009-2010 academic year. For this project, two electrical engineering students were asked to create a device that was to be used on a concrete canoe that the civil engineering students were working on. The EE students met with the civil students several times to discuss design parameters. As with the other projects, it seems from the paper that the civil students did not have much of a role in the building of the actual tool that was used on the canoe. This illustrates my point that many of these multidisciplinary civil engineering projects do not have much of a role of the civil engineering students.

A project that overcame issues with the size of civil and environmental engineering design projects was described by Sattler et al.[7] and Mattingly et al.[8], where an engineering senior capstone program at the University of Texas at Arlington was able to include a multidisciplinary senior capstone experience for civil engineering students. The project, funded through the National Science Foundation, was to design and build an on-campus biodiesel refinery. The authors reported the results of student satisfaction surveys related to the project.

Another opportunity for multidisciplinary team learning in civil and environmental engineering are service projects as described by Mostafavi et al.[9] and Grigg[10]. Local and international service projects can provide opportunities for civil and environmental engineering students to work in multidisciplinary teams.

This paper describes the development of a pilot multidisciplinary year-long capstone design project in the Department of Civil Engineering at the University of Nebraska-Lincoln (UNL) and our plans for evaluation and future expansion of this program.

Approach

Civil Engineering Capstone Design at the University of Nebraska-Lincoln. The typical senior capstone experience at UNL is a single semester. Students work in teams on a civil engineering related project which is typically an existing industry consulting projects that is typically in the 95-100% design completion, bidding, or construction phase by the time the students are introduced to the project. This allows the students to access existing detailed survey data and other project data, site design complications, and regulatory requirements. The student's final product is a 30% completion design report and an oral presentation to the client (the consulting firm who provided the project). While this senior design meets the ABET requirements, is a positive experience for the students, and has been part of a successful program for over a decade, there is still room for improvement. In the Spring 2018 semester, there are 23 students enrolled in the traditional civil engineering capstone design course

Description of the Multidisciplinary Capstone Design Project. For the 2017-2018 academic year, an alternative senior design experience was designed. The goal of this project is to design and construct a functional tabletop water treatment plant model. This alternative project is a two-semester project with a multidisciplinary team of two civil engineering and two electrical engineering students and is being supervised by faculty in the Department of Civil Engineering and the Department of Electrical and Computer Engineering.

The role of the civil engineering students is to design the water treatment portion of the unit including sizing the treatment units and calculating flow rates and weight requirements for the table that will hold the model system. One of the design constraints was that the entire demonstration should be completed within 30 minutes. The current design includes coagulation and sedimentation, filtration and disinfection. The electrical engineering students are designing the SCADA system that will control the unit. The SCADA system is run by a programmable logic controller (PLC) that controls the sensors and pumps. The sensors included in the system include sensors for flow, turbidity, etc. The finished table top model can be used by the Department of Civil Engineering and other environmental and water resources professional organizations for educational purposes (K-12 education and other community outreach activities). A diagram of the system is shown in Figure 1.

During the two semesters the students have given several presentations of the proposed project. These presentations were given in classes and at local engineering firms. After the presentations given at local engineering firms, the professional engineers and marketers in attendance gave feedback to the students on the project design, on their presentation slides, and on their speaking skills. The students have also submitted grant applications to public and private for funding.

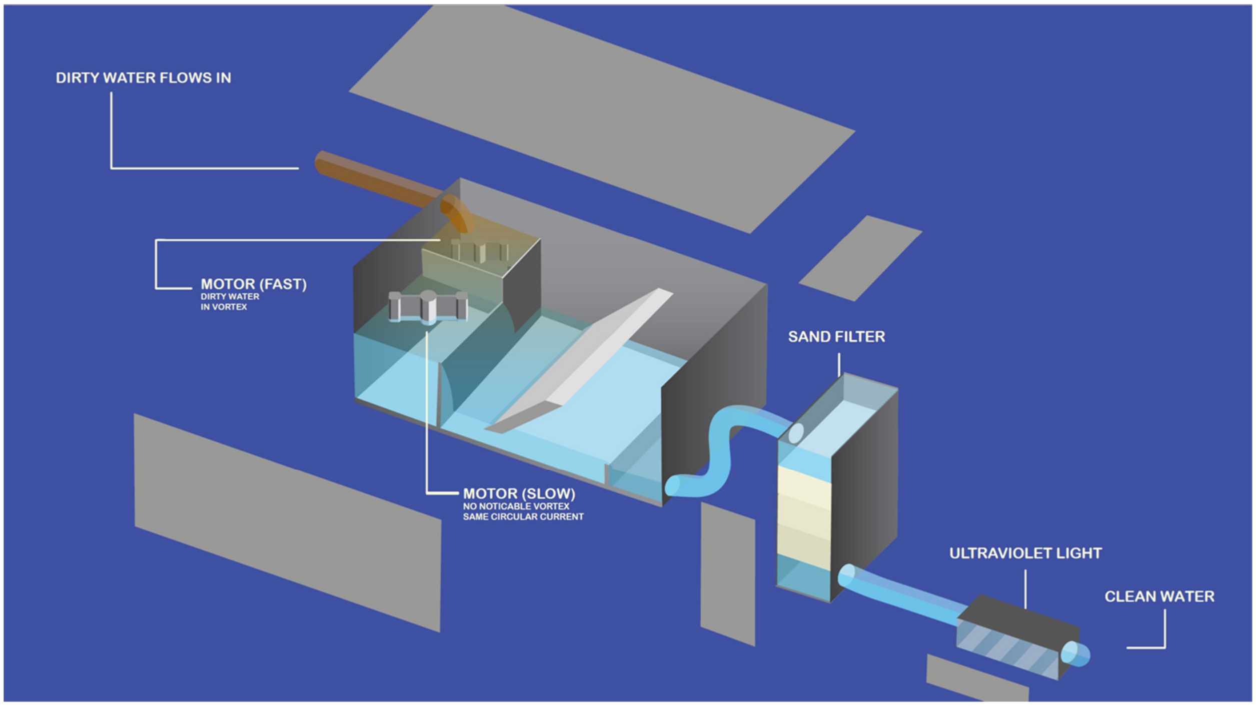

Figure 1. Diagram of the table-top water treatment model.

Multidisciplinary Design Evaluation. To evaluate the impact of the year-long multidisciplinary capstone design, we plan to conduct a student survey as described in Basha and Lee[4]. The survey will be administered to students in both the multidisciplinary year-long design and the traditional semester-long capstone design course at the conclusion of the Spring 2018 semester. The survey questions used by Basha and Lee[4] are:

Please rate the following items between 1-5, with 1 representing an item which is “not important” to you and a 5 meaning the item is “very important” to you.

1. Hands-on project experiences in the classroom
2. Group projects in the classroom
3. Interdisciplinary classes are part of your overall education
4. Interdisciplinary projects to your classroom learning

Please rate the following items between 1-5, with 1 representing an item which you “strongly disagree” with; and 5 meaning the item, which you “strongly agree” with.

5. I learn best when working with people from different disciplines
6. I learn best by working alone
7. I prefer exams more than project based classes
8. My experience with project based classes is extensive

9. My experience with interdisciplinary projects is extensive
10. I prefer theoretical to experimental work
11. I prefer to lead my group for group projects

This evaluation has not yet been conducted as this semester is still in progress. In May 2018, this survey will be administered to students in the traditional civil engineering capstone design (n=23) and the alternative senior design course (n=4).

Lessons Learned and Discussion

We have identified several important preliminary lessons learned through this experience. The first is that both groups of students learned the vocabulary and terminology of the other discipline, which they would not have been exposed to if this was a single discipline design, or even designed by subdisciplinary groups within civil engineering. For example, in the initial design phase, the civil engineering students created a preliminary design of the system using AutoCAD. Using these design drawings, they were able to communicate what was needed from the electrical engineering students regarding controllers and sensors.

In addition, because of the limited budget for this project (approximately $2,000), the students had to optimize the design, taking into account constraints from both the civil engineering and electrical engineering aspects of the design. One example of this was the number of 'items' that could be controlled independently in the system. The overall system design required four pumps and three motors, but the controller had only four channels. Two of the motors could be controlled at the same time, but the rapid mix motor needed to be controlled independently. That left only two slots for the four pumps. Since the peristaltic pump needed to be controlled independently, that meant that the three remaining pumps all had to be controlled the same way. The consequence of this electrical engineering design constraint on the civil engineering students was that they had to change the shape of the weirs to control flow from chamber to chamber.

Another example of interdisciplinary collaboration and cooperation was the calibration of the sensors within the system. The electrical engineering students needed information from the civil engineering students on how often the sensors needed to be "polled", or reported back to the PLC. The civil engineering students wanted a flowrate sensor to measure the flow and compare it to the design flow. However, given the flowrate, the sensor required microsecond polling, but the PLC system was set up for millisecond polling. As a result, the civil engineering students had to design a conveyance where millisecond polling would still produce accurate results.

Conclusions and Future Work

We believe our experiences in initiating an interdisciplinary capstone design experience provides valuable lessons learned for other faculty interested in similar experiences for their students. One of the challenges of this work was to identify projects that have a significant enough design component from at least two disciplines so that the joint project can meet the course objectives for capstone design in both disciplines. A second challenge is to identify projects that meet the course outcomes, but that also can be built at relatively low cost. In this project, our project budget was approximately $2,000 and included some in-kind donations for the electrical engineering equipment. We explored multiple funding options including support from engineering organizations and the college of engineering, and we involved the students in preparing and presenting their designs to help secure the funding. A third challenge in working collaboratively across disciplines is the logistics of meeting course deadlines and deliverables for two courses. The students involved in this project were enrolled in two different courses with the civil engineering students enrolled in a civil engineering technical elective in the fall semester and the civil engineering capstone design course in the spring semester. The electrical engineering students were enrolled in their year-long capstone design course. A final lesson learned is that not all students are initially interested in these types of alternative experiences, as only 2 of approximately 25 civil engineering students opted into the year-long alternative capstone design experience, which gave them credit for 2 courses, a one semester technical elective and a one semester capstone design course.

In the future, we plan to continue this interdisciplinary capstone design collaboration between civil engineering and electrical and computer engineering students. For the 2018-2019 AY, we have identified a project where we will partner with a state agency to develop a web-based application to display water availability and water demand data. The role of the civil engineering students will be to analyze the data and determine the best way to display the raw data and how best to synthesize the information. The electronics and computer engineering students will develop an app that will allow the user to see the raw data available on the website and display the synthesized data. We will administer the design evaluation survey with students that participate in both the alternative capstone design as well as the traditional semester long design project to better understand the impact of the interdisciplinary design project on student learning. We also hope to expand our partners to include more engineering disciplines, as well as non-engineering disciplines.

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