



Using Sponsored Design Projects to Strengthen Professional Practice Curriculum Components in Civil Engineering Capstone

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Abstract

The Civil and Environmental Engineering department at Brigham Young University has a professionally focused, two-semester capstone program involving 10-20 sponsors from the public and private sectors and undergraduate teams guided by graduate student-mentors and faculty advisers. As they are able, sponsors provide a financial contribution for the project work done by the team. However, the work is performed and provided to the sponsor “as is”, meaning that it is not stamped by a professional engineer and no warranties are given. Most sponsors return to the program each year, even as new sponsors have been added. The class is divided into teams of three or four students. The class is educated on topics relevant to professional practices such as team building and professional engagement, namely, Request for Qualifications (RFQ), Statement of Qualifications (SOQ), Request for Proposals (RFP), proposals, interviews, and contracts. They also study finance, project management, teamwork, leadership, and career development. Each of these topics is integrated by experience through the capstone project.

In the first semester, teams are formed and organized and experience first hand the professional engagement process. Teams respond to an RFP, are interviewed, and awarded projects on a competitive basis. The second semester begins with a kickoff meeting where the sponsor provides documents, direction, and expresses important ideas about what should be delivered. All of the design work is completed as an on-campus internship during the semester. Each team is mentored by a graduate student who represents the sponsor’s interest and is more capable of providing the continuous support necessary for the undergraduate design teams to stay on task. This mentor meets with the team weekly, helps plan tasks and time management, and ensures technical accuracy and sponsor satisfaction. A faculty member is also assigned to each team and is available for periodic consultation and encouragement to insure that best practices are implemented and a quality final solution can be delivered to the sponsor. Deliverables include an oral presentation, usually given at the sponsor’s place of work, a final report with drawings and specifications, and a poster describing the design.

Background

Capstone Objectives

Capstone courses have become a widespread culminating experience in undergraduate engineering programs. They are largely the result of engineering programs seeking to better meet the needs of industry and have become so important that ABET requires universities to include them ^[1]. Nevertheless, capstone programs vary widely from school to school and a single definition that applies to all programs does not exist. According to Fairchild and Taylor ^[2], capstone projects are “culminating experiences in which students synthesize the skills they have acquired, integrate cross-disciplinary knowledge, and connect theory and application in preparation for entry into a career.” Durel ^[3] offers another perspective stating that capstone can be seen as a “rite of passage or luminal threshold through which participants change their status

from student to graduate. A capstone course should be a synthesis, reflection and integration, and a bridge or a real-world preparatory experience that focuses on the post-graduation future.”

Academic Requirements

In today’s world many professors and college graduates have observed that it takes more than technical expertise to be a successful professional. A wide range of nontechnical skills are essential: leadership, teamwork, problem solving, decision making, critical thinking, interpersonal communication, and management. These types of skills are often referred to as “soft skills.” To help students develop both soft and technical skills, the objectives of a capstone course, project, or experience should typically include the following ^[4]:

- Provide students an opportunity to synthesize knowledge from formal and informal learning and apply such knowledge to contemporary issues in the field
- Help prepare students for a successful career by providing experiences that enhance their labor market advantage
- Increase students’ understanding of the “big picture” including ethical and social issues related to the field
- Help students understand the relevance of theory and research to practice
- Provide opportunities for teamwork and leadership

Because of the importance of capstone programs, ABET has delineated key components that these programs must have to be valid capstone experiences and to induce students to develop and apply both soft and technical skills. ABET has emphasized the need for engineering capstone courses to build teamwork, communication, and project based skills. Furthermore, ABET has required that students have an ability to function in multidisciplinary teams and to design a system to meet desired needs within realistic constraints. In summary, ABET states that “students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints.” ^[5]

In order to meet important educational objectives outlined by ABET and ASCE, the BYU CE department, similar to other CE departments, is trying to provide graduates with the best possible preparation for professional practice by enhancing the capstone program. Over the past 15-20 years, the BYU CE senior design has been through several transformations motivated by increased emphasis on culminating experiences as well as feedback from students and alumni. An important crossroads came in 2009 as we struggled to improve the capstone program while simultaneously strengthening graduate opportunities in leadership and business practices.

2009 Alumni Survey

Recognizing the importance of developing business practice skills, a comprehensive survey was conducted of all BYU CE alumni to evaluate the program’s performance in teaching these skills. Results from more than 450 respondents, shown in Figure 1, revealed that the department’s greatest weakness was developing professional practice skills.

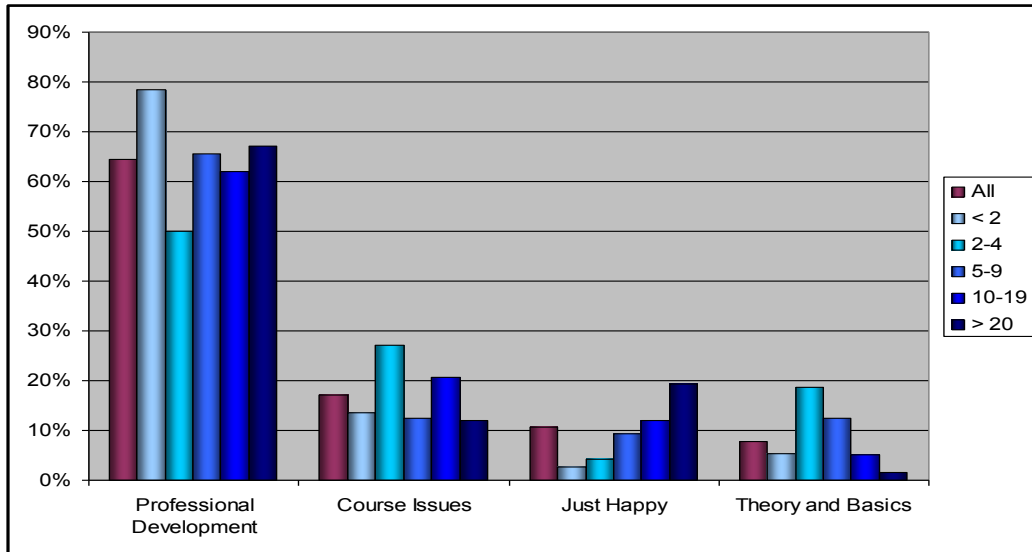


Figure 1. Suggested improvements grouped in years since graduation.

The open-ended questions survey asked respondents to indicate the greatest weakness of the department. For the purpose of understanding the answers better and establish possible trends, all responses were sorted into the four categories shown in Figure 1. Overwhelmingly the alumni indicated they were well prepared technically to practice civil engineering but not as well prepared for professional practice. They desired more experience working on real projects and managing projects and people along with a better understanding of developing work. They didn't understand how to work through public entities that often are the clients and/or the gatekeepers of large projects and desired to learn more about bonding and other mechanisms that fund civil infrastructure. The results of the survey supported the decision to develop a program to take the place of the former management minor at the graduate level. In doing so, and as a means of leveraging faculty resources we endeavored to define the graduate management and leadership experience in such a way that it could also strengthen the undergraduate capstone program.

Program Overview

The redesigned current CE capstone program at BYU spans two semesters and involves undergraduate and graduate students. Graduate students take classes in civil engineering business operations, project management, and leadership while mentoring teams of undergraduate capstone students. They work closely with project sponsors to acquire knowledge about a capstone project and prepare requests for proposals with a rough scope of work during the fall semester. Undergraduate student teams, while learning the fundamentals of professional practice, develop proposals for the projects in response to a Request for Proposal (RFP) during fall semester. Each team then completes the work (in what is called *on campus capstone internship*) during the winter semester with the help of the assigned graduate student mentor, who is already familiar with the specific project. Project sponsors are asked to participate as a minimum in a kickoff meeting, evaluating progress at midterm and the final result, though they are free to be as involved in mentoring as much as their time and interests permit.

The main objective of the capstone program is to provide an opportunity for students to develop higher order thinking skills. Students learn how to analyze, evaluate, and create while learning the professional practice skills such as economics, sustainability, project and people management, and client retention that are necessary for successful business practice.

Projects and Sponsorship

Who are the Sponsors?

The sponsors have become acquainted with the program in a variety of ways, and they represent both public and private entities. Most of the sponsors were contacted by a faculty member in the department and received an offer to participate in the program, while others have solicited the program director for an opportunity to be involved. There are a few sponsors who were recommended by those who had participated as sponsors in a prior year.

Some of the previous sponsors from the public sector include Salt Lake County, Springville City, Bluffdale City, South Jordan Water Conservancy District, and Riverton City. Sponsors from the private sector include Rio Tinto, URS, Kleinfelder, Atkins Global, and The Church of Jesus Christ of Latter Day Saints – Special Projects and Civil Engineering. Some of these sponsors have collaborated on multiple projects per year and some have been working with the program since its inception in 2008.

Based on feedback from the sponsors, they enjoy two principle benefits. First, they find that when the proper project is selected and the scope defined to fit the student constraints, the work is valuable. Essentially, they do the same technical work that would be done by an entry level engineer, with the exception of some of the field work requiring specialized equipment which may not be available. Second, it is enjoyable for them to be able to work with the students and to provide an experience that is exciting for them. The arrangement also provides sponsors with an opportunity to evaluate capstone team members as potential full-time hires upon graduation.

What are the projects?

The projects come from all the major disciplines of civil engineering. Typically, the sponsors have projects that are geared more toward one of the disciplines. The municipalities typically have projects focused on water and transportation engineering while private companies have more projects in structural and geotechnical engineering. The annual cycle of the capstone program requires that projects be identified by August. Projects are completed in April the following year. Therefore, sponsors look to projects that they have not begun working on themselves, or that are not currently a top priority for them. Most projects fall in the category of feasibility studies and provide sponsors with an idea of whether they want to pursue a full design and implementation or which of several alternatives might be the most feasible. Where sponsors may have flexibility in which project they choose, an effort is made to ensure a good mix of projects from each civil engineering discipline will be available to the students. In the past, there have been more water and transportations projects available than structural, geotechnical, or environmental projects.

The scope of the project is defined in collaboration with the program director and refined as the graduate mentors are introduced and assume responsibility for developing an RFP. Recently, much of the project development phase of the program has been entrusted to a graduate student who had previously been involved in the capstone class as an undergraduate. The full scope is not defined in the initial stages of project development, but some of the requirements specific to the project are discussed based on technical difficulty, equipment, and time considerations. The projects should be scoped for approximately 300 man-hours (the combined hours that the student team should have to dedicate to the project for a team of 3 people working 8 hours per week for 13 weeks.)

Some of the previous projects include the following:

- Floodplain mapping and mitigation plan development and evaluation
- Roadway intersection and traffic control design and evaluation
- Water treatment and distribution systems design and evaluation
- Stormwater conveyance systems design
- Steel frame bracing and small frame designs
- Geometric roadway design
- Footings and foundations design

Projects assigned for the current year include designs for the following:

- Bearing column replacement design
- Highway slope stabilization design
- Drainage route near a lake design and evaluation
- City tank and pumping addition design
- Geometric road reconstruction design
- Traffic intersection design
- Channel modification design and evaluation
- Storm drain design
- Structural hoist design
- Water treatment and distribution for a camping facility design
- Storm and runoff analysis

Projects results are documented online at <http://cecapstone.groups.et.byu.net/> where there is a complete list of the current and past projects with brief descriptions and related documents.

What legal/financial interaction exists?

In the original pilot of this capstone program there was no financial or formal agreement between the university and the sponsor. It is understood by all parties that the work performed by the students is presented “as is” with no warranty or liability, meaning that it has not been stamped by a professional engineer. In an effort to provide overhead funds for capstone teams and the

department, a financial solicitation was made to sponsors for the first time in 2013. Each sponsor has been asked to provide \$1,000 to the civil engineering department for each project. These funds are used for teaching assistants, travel needs, printing and other supplies. Most sponsors have funds available for this kind of agreement, and where the policies of the organization allow, the sponsors have all been happy to commit this amount. One sponsor, after one of their projects was completed, was so pleased by the work that he voluntarily paid for the work done by the students, and suggested that they would always be willing to do so. There were some cases where sponsors were unable to get approval for the funding. These were typically large private firms with strict budgeting policies. Due to a large pool of interested sponsors, it is anticipated that only sponsors who are able to make financial commitments will be involved.

There is little legal agreement between the sponsors and the university. There is a non-disclosure agreement available if the sponsor desires, and there is a university approved contract describing the purpose of the project, how the results should be treated, and how finances will be received.

First Semester

Professional Engagement

One of the primary purposes of the capstone class is to have a professional experience rather than only technical training. There are two courses with this intent: an undergraduate course and a graduate course. The graduate course is comprised of students who already took a culminating design course. They act as surrogates to the sponsors throughout the project design and as a mentor to the undergraduate team.

At the beginning of the year, the graduate students are presented with a list of the selected projects for the year. They are assigned to a specific project and begin by meeting or contacting the sponsor to get a sound understanding of the project and together they finalize the scope. With that information, the graduate student prepares a Request for Proposal. The graduate student is able to write an RFP that is similar in content to a professional one. Each RFP is then made available to students by the middle of the fall semester.

Once the RFP's are posted, the undergraduate teams review them and decide on a project that they would like to propose on. The teams are made up of 3 or 4 students who choose to work together. Where more than one team proposed on a single project, a competitive model is used to award the project based on the quality of their proposal and their qualifications. Over the next month or so the students submit a Statement of Qualifications (SOQ), (though there is no Request for Qualifications or short-listing process,) a proposal, and a video interview targeted at the project of their choice. Three graduate students will evaluate and rank each project after which the projects are awarded in mid-November. The students finish the semester by writing a short contract detailing typical academic expectations, which include a kick-off meeting, 50% reports, final reports, a poster, an oral presentation, and other project specific milestones.

Professional Lectures

The class lectures are given by faculty and working professionals. They are invited to lecture on specific topics relative to their experiences in project development and management in civil engineering. They lecture on the following topics: résumés, team building, professional engagement (RFQ, SOQ, RFP, proposals), interviews, sustainability, the time value of money, the ASCE code of ethics, contracts, leadership, and time management. There are some assignments involved with these lectures, but most notably in 2013 there was an electronic forum-style discussion in which many of the students discussed what they learned from the lectures and other information they might have on the topic.

Academic Integration

In some ways, one of most difficult challenges in this type of class is tying the lectures to the work that the students are doing. A lot of effort is put into the timing of these lectures. For example, the goal would be for the students to have a lecture on proposals the week before they will be writing one. In large part, this is possible during the first semester, but a perfect correlation is not possible.

Academic Collaboration

Team Formation and Strengthening

Working in teams is something to which many students are averse, and yet it defines much of the professional workplace that they are preparing for. They find the dependency on other students uncomfortable and the communication difficult. Some have reported a strong distaste and near dread of having to work with a team for an entire semester. Others are excited at the opportunity to do a project that is too big for them to do by themselves. Learning how to work in teams is a primary purpose of the capstone program.

During the first semester, the teams do only a few things together – the proposal and the interview. They given a lecture that discusses teamwork, and different personality types, and they read a book on interpersonal relationships.¹ These smaller activities help introduce the team members to one another and may reveal some of the difficult team dynamics. At the end of the first semester, the teams are invited to conduct a 360 degree survey which should help them understand some of their strengths and weaknesses from which they set goals to achieve better individual and collective teamwork. They do not survey their team members at this point; however later in the semester team members provide specific feedback to one another. As the second semester starts the team meets to discuss and set goals by which they will measure themselves throughout the internship semester.

The Graduate Mentor

The role of the graduate student is important to the learning experience of both the undergraduate team and the graduate student themselves. They are also key to the sustainability of the hands-

¹ Books that have been assigned include “Leadership and Self-Deception”, among others.

on, real world projects by serving as team-specific teaching assistants. Without them, the time demands on project sponsors and faculty advisers would be too heavy and successfully mentoring the capstone teams would be very challenging. The graduate student may or may not have expertise in the technical content of the project. Therefore, it is not requisite that he/she be a technical tutor of some kind, though they do have experience from the preparation of the RFP and may point the team in the right direction or provided helpful materials. The idea of a mentor is also different from that of a project manager. The graduate mentor is not intended to be heavily involved in the design of the project or in time-management, but rather to provide encouragement and see that the team continues to function well.

The graduate mentor helps the team function effectively by providing frequent support for both technical and non-technical issues, and to ensure that the sponsor's expectations are being met. The mentor meets with the entire team once a week for an hour to facilitate individual work reports, create an atmosphere of accountability and respect, guide or direct ideas for design, and to answer their questions. These roles are explained and discussed with the graduate mentors in detail. This experience is valuable to both the mentor and their team. Because the mentor is the primary contact for the team, it is important that they meet on a weekly basis.

The sponsors are typically very busy and do not have time to answer questions about preferences, project details, etc. It is essential that the mentor take ownership of the project, meaning that they should understand the desired outcomes and the intricacies of the project, and they should have all necessary data and information from the beginning. When something unexpected comes up, it should be the mentor that communicates with the sponsor to discuss a solution. Putting these responsibilities on the mentor rather than the sponsor or a faculty member is a huge benefit and makes the program sustainable.

The Faculty Adviser

Each project is assigned a faculty adviser by the department chair in collaboration with the capstone director. This faculty member does have some technical expertise in the project content, and ideally has considerable experience, though there is not always a perfect match. In fact the best source of project sponsors are colleagues and associates of faculty members and having each faculty member develop and foster a relationship with a capstone sponsor is an ideal way to encourage the faculty to support the program. Teams typically meet with the faculty adviser two to four times during the semester. This can vary depending on the level of mutual engagement that occurs. They may also help the mentor define the scope of the project as the RFP is written. The faculty adviser is specifically recommended to attend the kick off meeting, to review the 50% report and give feedback, and to review and/or attend the final presentation to the sponsor.

Second Semester

An On-Campus Internship

A primary purpose of the capstone program is to provide a professional experience and is run much like an internship from campus. During the second semester each student is asked to clock eight hours per week working on the project, three of which should be during the same time as

their teammates including their weekly team meeting. Any time spent related to capstone is included in these hours. Thus, over the approximately 14 weeks in the class, they are expected to log over 100 hours each. The class as a whole only meets on a monthly basis to stay on track by reviewing assignments, answering questions, and discussing learning experiences.

The Design Grind

One of the challenges of the autonomous nature of the course is ensuring that the project is progressing in the way it should. In the sometimes monotonous patterns in each semester, it could be easy for a team to fall behind or veer off track or to even lose track of one of the team members who is not willing to take responsibility for their assignments. In order to avoid these downfalls and to be successful, there are a few essential practices that each team should establish.

First, there should be a strictly scheduled, one-hour meeting time every week. The graduate mentor also attends this meeting, and the purposes of this meeting is to give an account on the completion of assignments and work tasks, discuss ideas for design and questions related to the team or the project, and make work plans for the week to come. These meetings are indispensable to fostering the development of high functioning teams.

Secondly, there should be well-established means of communication. As a good example, it is common for team members to call or text one another to quickly discuss what they are currently working on, in addition to emails. Furthermore, the teams are encouraged to centralize their documents, including work logs and task lists such that they can be viewed simultaneously from different computers and remain organized. Some teams have used shared network drives and cloud software and storage tools such as GoogleDocs and Dropbox. These tools help team members keep track of one another's progress and increase their ability to work as a unit.

Deliverables and Presenting

The highlight experience for the capstone students is to present their project to the sponsor in a professional setting. Each team, mentor, and faculty adviser should go to the sponsor's work place to submit a hard copy of their final report and make a brief oral presentation of their design. This presentation, including both a poster and a digital presentation, is an important feature in the professional experience. Other deliverables submitted with the final report include items defined by the project sponsors like cost estimates, drawings and specifications, and other recommendations. The sponsors review these materials, and then provide feedback on these deliverables, the final report, and the entire two-semester project through a survey done by the capstone director.

Conclusions

While a planned follow up alumni survey has not been conducted yet to measure the effectiveness of the program, students comments indicate that important capstone objectives are being met.

I learned a ton in capstone! It bridged the gap between the classroom and engineering practice for me. It got me out of a world where I am given a problem and told what to solve for, to a world where I had to identify the problem, and decide what to solve for. It was also really useful to experience doing engineering work in a group setting.

This class is a blessing in my life. It has provided me with valuable teamwork and technical experience that have made me more confident in my engineering abilities.

The class was exceptional and I would like to thank the professors for all you did to make our project a success. I think capstone, if taken seriously by the students, will enable them to have a more practical engineering experience. They need to have confidence that they can exceed the client's expectations. One thing I can say about this project is that I put all of my heart and effort to make it happen. I don't really care how I am graded but how pleased my sponsor was when he visited our booth during the presentation day.

I learned a great deal in this course. It is a good idea to provide seniors a real world design opportunity.

The program described provides a valuable professional experience to undergraduate students and graduate students alike. Important to this experience is the involvement with the project sponsor, graduate mentor, and faculty adviser in addition to the necessary technical design. Also valuable is the emphasis on autonomy and teamwork, and the creation of professionally prepared design deliverables. The students and the sponsors alike have enjoyed the opportunity to work together in this unique environment, and have found it a mutually beneficial experience.

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