BYU Civil & Environmental Engineering Capstone Program

Wayne Y. Lee, E. James Nelson, M. Brett Borup
Brigham Young University / Brigham Young University / Brigham Young University

Abstract

The Civil & Environmental Engineering Capstone Program at Brigham Young University initiated new program enhancements in 2016. The main objective of the enhanced Capstone Program is to extend students' learning experiences by providing them an environment that fosters practical "soft-skills" beyond classroom experiences prior to entering their respective professional work fields. These practical soft-skills help encourage innovations, team dynamics, leadership, customer/vendor/management interactions, project/time management, business operations, acceptance of personal responsibility, and conflict resolutions. All of which are important and desirable attributes that will help ensure successful integration of graduating students into their respective work environment while reducing potential employers' uncertainties involved in hiring these new college graduates.

Innovative approaches applied to achieve the program's objective include: (1) The implementation of a management team consisting of "non-academic" licensed professional engineers working side-by-side with faculty and professional advisors which reduces the load of full time faculty members; (2) improvements on request for proposal, proposal, project execution, and project management processes to more closely mimic "real world" situations; (3) development of an online "win-win" environment that showcases students' project and performance skills while providing potential employers an opportunity to preview their future employees beyond normal interview and resume review process; and (4) enhancements on project focuses that allows student teams to innovate concepts that will improve project sponsors' "bottom-line" profitability and competitiveness while encouraging future project participations.

Successful completion of the first year's thirteen projects provided invaluable insights for the program's future through responses and feedbacks from students, faculty, professional advisors, potential employers, and project sponsors. Incorporation of these inputs will help develop a program that will be mutually beneficial to students, potential employers and project sponsors.

Keywords

capstone, professionalism, win-win, soft-skills, responsibilities

Introduction

In today's professional world, competitiveness, adaptability, trustworthiness, quality, reliability and profitability are keys to survival, which eventually translate into employment security. In order to maintain competitiveness, technical skills are often overshadowed by employers'

perspective on whether a given engineering employee also has the ability to bring in new businesses in order to help improve the financial bottom line of the company.

In most engineering projects, a relatively small amount of an employee's time is spent on technical work to satisfy the requirements for the project deliverables, whereas a majority of time is often spent on meetings, documentations, presentations, and other non-technical tasks. As a consequence of this business perspective, engineers must also gain the ability and experience to manage, document, communicate, and work with diverse non-technical (and sometimes adversarial) conditions in order to help improve the company's profitability and competitiveness. They must also learn to adapt to everchanging business environments and practices, with seemingly endless government regulations and, of course, the politics associated with each project. These additional project-critical skills outside of normal technical and engineering skills are often referred to as "soft-skills". The harsh reality is that while technical skills open the door to professional engineering practice, these "soft-skills" are critical for survivals and long term successes in the professional world.

Many of the graduating students entering the engineering fields possess very limited, if any, practical soft-skills if they have never been introduced to a practical project environment. As a result, these new engineers often struggle to fit-in as they climb a steep learning curve on the job. Those that are experienced with, or at least exposed to, the practical project environments are better equipped to handle the everchanging circumstances, which can be a game-changing matter in relation with their employment security. Those who think outside the box and are adaptive to changes can provide greater calming assurance to both the employer and the respective customers. Furthermore, engineers that can handle challenges outside their field of expertise are also more likely to progress faster and further toward their career objectives.

With the competitive work environment in mind the necessity of introducing practical experiences to graduating students becomes imperative. A Capstone Program is one way for students to experience a real world work environment – sometimes with politics and all.

The Civil & Environmental Engineering (CEEn) Capstone Program at Brigham Young University has initiated major enhancements since the beginning of the 2016-2017 academic year with an emphasis in introducing students to an environment requiring the use of these soft skills. These enhancements were built upon the foundational program and curriculum developed by Dr. James Nelson et al.[1,2]. The majority of the enhancements occurred and continue to evolve from lessons learned in the project execution and management aspect of the existing Capstone Program, whereas the academic (i.e. course) portion of the program has experienced minimal changes in the program's inauguration year.

Capstone Program Challenges and Obstacles

If implemented properly, a Capstone Program can be an effective means to allow students to experience invaluable professional environment in a guided educational setting. In other words, Capstone Projects allow students with limited or no experience in actual professional work to practice with the guidance and mentoring from technical advisors and colleagues. In a Capstone

environment, students can learn from their mistakes as they fulfill their project tasks without fear of retribution from their employer for any potentially costly mistakes. Capstone after all, is a medium designed to encourage students to step outside of their classroom comfort zone and extend themselves to accomplish something they are not familiar with. There are, however, challenges associated with the implementation of a self-sustaining Capstone Program. BYU's CEEn Capstone Program is no exception from such challenges and examples of such challenges are presented hereafter.

All Capstone implementers must realize that if the students are to gain practical professional experiences in developing soft-skills, the Capstone Program should not be just another course that uses the same homework type projects and/or problems each time the course is taught just to practice technical skills learned from previous courses these students have taken. These types of courses will provide practices to what was taught in college but with little practical soft-skills development opportunities such as client and vendor relations.

A typical challenge often encountered by Capstone instructors is the students' attitude toward projects in the Capstone course that may be viewed as "busy work" or some sort of additional homework assignments during their graduating year. A student may feel that the completion of a Capstone project is merely a check the box requirement to graduate. In order to improve the effectiveness of the Capstone Program, the implementer must derive a way to help students take ownership and responsibility of their respective projects, and that their performance on the project will help them become more marketable with greater exposure to potential employers.

Another often encountered challenge is finding proper sponsors and funding that are meaningful in helping students learn practical skills, especially within a field like Civil Engineering where a majority of the traditional work is based on public agencies and small consulting firms with limited budgetary resources instead of larger manufacturers or agencies with funding for educational collaborations and research found in other engineering disciplines. In such cases, resourcefulness in seeking funding sources among non-traditional but related work arena is crucial for the development of a self-sustaining Capstone Program. BYU's CEEn Capstone Program utilized some of the concepts successfully proven in actual work environments as a basis for an enhanced self-sustaining program in a field with traditionally limited funding sources. The following sections describe the concepts and approaches implemented, or in the process of being implemented, to enhance the CEEn Capstone Program at BYU toward a sustainable program that will help students develop crucial soft-skills that will make them better leaders in today's professional practice.

Capstone Program Objectives and Implementation of Enhancements

The main objective of BYU CEEn's enhanced Capstone Program is to extend students' learning experiences by providing them an environment that fosters the development of practical soft-skills beyond classroom experiences prior to entering their respective professional work fields. By doing so, the program can help increase graduating students' probabilities of success in their professional field of choice upon graduation. Examples of some of the common and crucial soft-skills learning opportunities applied to our Capstone Program include:

1) <u>Individual and team innovations</u>

   Unlike homework problems where specific solutions are known in advance. There is seldom in an actual professional engineering project a well-defined and known solution. In fact, deliverables for engineering projects are often a result of choices made based on controlling factors from sometimes conflicting requirements, constraints and other project specific conditions and limitations. Students must learn how to think outside the box as they prepare to support such projects in the field. Innovations can provide the competitive advantage in winning project proposals and new businesses. All of our 2016-2017 projects require students to come up with alternative solutions that would meet or exceed their sponsors' requirements and expectations. Many require trade studies based on known project requirements, limitations and constraints. Some teams also had to select the best solutions based on both the know constraints and potential risks associated with each solution choice. The diverse criteria and skills necessary to successfully execute these projects highlight the importance of teamwork and help students gain an appreciation for the need to form strong teams and work cohesively.

2) <u>Accepting challenges outside of one's chosen field</u>

   Typically, each year we have between 10 and 20 Capstone Projects. The number of projects accepted for a given year is a function of the number of students available to take on these projects. Our Capstone students are advised to take on projects that are outside of their chosen field of study, or at least really stretch their technical backgrounds. For example, a water resource student is asked to choose a project in another Civil Engineering discipline such as geotechnical, structures, transportation etc. The rationale behind this approach is to encourage students to be flexible and adaptive as they prepare to enter their profession. Additionally, they will gain invaluable project experience in a discipline outside of their own.

   In practice, when one's chosen profession is encountering a down-time, which happens from time to time, those who are versatile in adapting to projects in other disciplines are more valuable to their company. Additionally, a potential employer is more likely to hire those who have demonstrated their ability to successfully complete a project in a discipline outside of their own chosen field of study. Furthermore, a typical Professional Engineers' (PE) exam is a measurement on how well a potential engineer can handle problems in multiple disciplines within a specific branch of engineering. One who only studies and focuses on a specific discipline is less likely to pass the PE exam. It's a win-win situation for both the student and their potential employer.

3) <u>Project planning, organization, management, and execution</u>

   In order to complete a successful project, one must learn the process of project planning, organization, management and execution. Without the ability to plan, organize, manage and execute, an engineer's upward mobility is limited. Each of our project consists of a team of 3 to 4 undergraduate seniors with a graduate student mentor (or project manager).

To facilitate assistance to student teams during project life-cycles, a CEEn faculty member is assigned to provide technical guidance for each project team. Additionally, a team of 7 non-faculty professional advisors (all registered and practicing PE's and SE's) are available for providing additional guidance to help mitigate any non-textbook challenges on an as-needed basis for the student teams. Six of the 7 professional advisors are also members of the CEEn Capstone Advisory Committee. The goal is to have student teams manage their own schedule, task assignments, challenge mitigations, and other project matters while providing guidance and professional advise as necessary. This arrangement of professional advisors to the student project team mimic project practices in the field.

Members of the Advisory Committee also give presentations during regular weekly classes on various aspect of a professional project practice from a practitioner's perspective. These presentations are designed to help all student teams recognize common project challenges while showcasing projects and results in relating field being done in practice.

At the start of a Capstone project, both the student team and their respective graduate mentor meet with their project sponsor for a kick-off meeting during which the sponsor provides the necessary project information including requirements, time/budgetary constraints and expectations for deliverables.

The graduate mentor will then prepare a project request-for-proposal (RFP) within two weeks based on the descriptions he received during the kick-off meeting. The RFP will then be sent to the sponsor for approval, with corrections as necessary. This step is to ensure that the sponsors' project information is being received by the students correctly and that both parties have a common understanding on what needs to be done to accomplish the project goals.

Once approved, the RFP is sent to the student team to prepare a full proposal describing their proposed course of actions toward the successful completion of the project. Each student team has a maximum of two weeks in preparing and submitting their respective project proposal. Once the proposal is accepted and approved by the sponsor, it serves as the written document of the project's scope, requirements and deliverables. The student team can then begin their project work with regularly required status reports, meetings and communications with their respective sponsor as necessary until final deliverables are presented and accepted by the sponsor. **Figure 1** shows a summary schematic of our Capstone project execution process which the student teams and their respective graduate mentor are required to follow throughout their project life cycle.

The two-week preparation time applied to both the RFP and the corresponding project proposal are designed to mimic typical RFP and proposal preparation and submittal time in practice. In many cases, proposals are due in less than two weeks in actual practices.
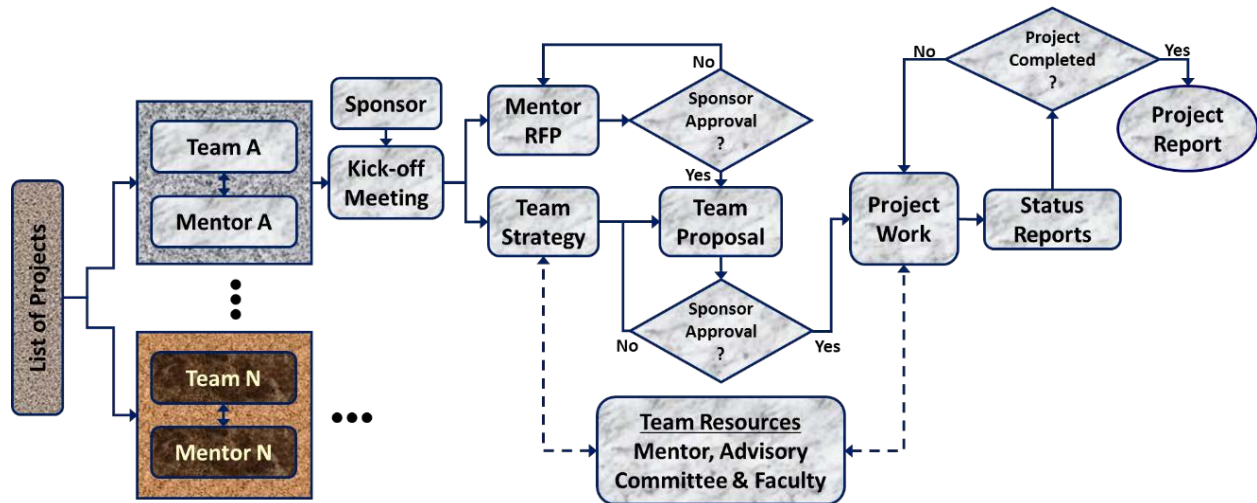
Figure 1   Summary of BYU's CEEn Capstone Project Life-Cycle

4) <u>Continuous product quality, effectiveness, efficiency and reliability improvements</u>

During each project cycle, each student team is encouraged to identify potential ways to improve project outcomes that would be beneficial to the sponsoring organization. Perhaps ways that can cut project costs while improving the quality of deliverables. In practice, continuous improvements are encouraged to help the respective company maintain its competitive edge in winning future projects.

5) <u>Time and budget management</u>

From an employers' perspective, time and budgetary requirements are probably the most crucial objective for every project other than the actual deliverables to be accepted by the customer. When a project exceeds its allocated time and/or budget, the company suffers financially. In some cases, customers may even penalize financially those who do not meet time and budgetary obligations. To help encourage student teams in satisfying time and budgetary requirements, each project team is required to submit a project management plan with important time line and milestones for task completions. Along with regular status reports documenting challenges encountered; challenge resolution as a team; schedule impact due to these challenges; and project status. Each team is required to notify their respective sponsors should any unexpected delay occur due to unforeseen project challenges. They are to work with the sponsors, technical advisors and faculty advisor to come up with a proposed path to resolution as necessary. Although every team encountered some sort of obstacle or challenge that pushed many of the respective team members outside of their comfort zone, thankfully none of the project teams encountered challenges that became a show stopper during the 2016-2017 academic year,

6) <u>Team dynamics and conflict resolutions</u>

In practice, conflicts often arise due to diverse personalities, differences in opinions, differences in interpretations of project requirements and expectations etc. A divided team

typically has a difficult time achieving project goals. One of the most challenging aspect of any given project is to get all team members to work together to accomplish the team's common goal of carrying the project to its successful completion, and there are no exceptions with student teams. Capstone projects are a good way to allow student teams to gain experience in how a team must pull together, regardless of differences, in order to achieve the project's objectives. Each of the 2016-2017 teams rose to the occasion in completing their respective projects despite differences among some of the team members.

7) Customer/vendor relationship and communications

Many projects come to fruition as a result of good customer relations established from prior project collaboration experiences. Trust and respect are something that can take a life time to earn but can be destroyed with just one undesirable incident. Unfortunately, many profit-driven and profit-focused employers often mistakenly ignore the importance of customer relations. A project is hindered if an employee with a good and established relationship with a project's customers is removed from the project and replaced by someone who is not familiar with the project nor the customer. The consequences of such actions can be severe. To help student teams to develop good relationships with their sponsor, many of whom may become their future employers, each team has minimum communication requirements. Status reports submitted monthly to the sponsor are required to develop and maintain a good working relationship, while keeping the sponsor informed of project status and any unexpected obstacles. Responses from sponsors concerning status reports have been positive as they appreciated regular updates on the progress of their projects. **Figure 2** shows a typical status report sent to the respective project sponsor on a monthly basis. They are purposefully brief, respecting the limited time of sponsors and others to read and provide feedback and force students to learn how to communicate only the essential.

Figure 2   Sample Capstone Status Report

8) Mitigate effects of organizational/governmental politics, regulations, & restrictions

Each project has its own politics and challenges. Those who can navigate through these challenges are successful in fulfilling their project obligations. Some of politics, if left unresolved, can grow to become show stoppers toward the successful completion of the project. For example, one of the 2016-2017 projects dealt with traffic-regulation changes at a specific intersection that may potentially affect traffic in neighboring streets. To ensure a common ground with compromises from all those involved, the city must work closely with residents from nearby neighborhoods prior to project initiation. Project results and conclusions by student teams must account for concerns expressed by those involved.

9) Mid-course adjustments and adaptations to overcome unforeseen obstacles & challenges

There are times mid-way through a project when team members and/or sponsors realize through status reports or some other means that the direction the team is heading may not lead to the best results due to unforeseen obstacles. Mid-course adjustments are necessary to realign the project path. These types of scenarios can happen regularly in projects, which is why communications with customers and vendors are essential to determine what adjustments and course of actions are necessary to achieve the best project outcomes. At least one of our Capstone projects required some collaborations with their sponsor for mid-course adjustments due to site access limitations caused by unusual and harsh winter weather conditions. With assistance from their engineering sponsors, they were able to complete their project tasks using similar data obtained previously by the project sponsors.

10) Minimization of project scope creep

Another common scenario during project execution is that the customer can suddenly realize that by adding a couple of new tasks, additional desirable project objectives can be achieved to provide the customer greater benefits and/or profitability. In such cases, customers may not recognize the unforeseen impact of expanding the original scope of the respective project. In most cases, scope creep can be detrimental to project schedule & budget. For Capstone projects, it is vitally important for students to learn to stay with pre-agreed tasks except for necessary mid-course adjustments that either have negligible impacts on the project schedule and budget, or actions that are necessary to complete project tasks due to unforeseen obstacles. One of our student teams did receive requests from their sponsor to add new items to their original proposed and pre-approved task list, which at the time appeared to provide additional desirable information for the project sponsor. Upon investigation, the student team determined that such a scope creep would result in a major delay toward the completion of the project. Upon explaining to the project sponsor the delays such additions would cause, they agreed to drop the request.

11) Acceptance of project ownership, responsibility and decision consequences

One of the major challenges encountered in a Capstone Program was to help student teams recognize that their work can result in tangible returns toward their own future. It is also important to encourage them to take ownership of their project work and personally accept

responsibilities and consequences for what they have accomplished. Utilizing the same principles applied to social media, BYU's CEEn team decided to show-case all of our student teams' work on the new CEEn Capstone website with pre-agreements among sponsors, student teams and CEEn Department. All RFP's, proposals, reports and presentations are posted on the website with the exception of any information that has been pre-determined by the respective sponsors to be non-disclosable due to proprietary, export controlled or other contractual reasons. By posting student teams' work in progress, the following tangible "win-win" benefits are realized:

- Enhanced communications with project sponsors as project sponsors can review and comment on work in progress by their student teams in accordance with their availability and schedule

- Encourage students to take ownership and accept personal responsibility of their project work as their work progress and results are in public display for all to see, especially by project sponsors and potential employers. Posting work in progress also helps students to recognize that their work is important enough to be showcased online and not just another homework assignment. The realization that higher quality work and attention to details will help improve their marketability as they seek permanent employment is an excellent motivator for students to take ownership and responsibility of their own work.

- Students can use their posted work in conjunction with their resume during job interviews by inviting interviewers to see their project work first hand, which can greatly enhance the desirability for potential employers to consider. Feedback from several students at year-end were positive as their recent job interviews focused on their Capstone work which they are proud of and is unique from typical classroom experiences. Their potential employers were excited to see how an employment candidate performed in an actual team project environment.

- Encourage collaborations and sharing of ideas/information on non-proprietary and non-tightly controlled engineering projects that can help improve the overall quality of future products through lessons-learned posted on the Capstone website. An excellent public service provided through academic programs. For example, Spanish Fork City's desire to freely share their experience with the effectiveness and lessons learned on their innovative approach to low impact development (LID) through our Capstone Program with other municipalities can help improve the overall quality of other municipals' LID implementations. Spanish Fork City can then gain some invaluable insights from others in return as they implement their own versions of LID. This sharing of information is crucial as LID will become a requirement in the near future by the EPA and the State of Utah for all new development projects.

- Reduce potential employers' uncertainties and hiring risks toward specific candidates based solely on resumes and interviews. Being able to see how a specific candidate they interview performs in a real-world team project

environment is invaluable in helping employers making hiring decisions. We received positive feedback from sponsors and potential employers on making such information available to them. **Figure 3** shows the link to each of the 2016-2017 CEEn Capstone Projects which potential employers and project sponsors can access at their own leisure. Upon clicking on the link (blue underline texts) for a project of interest, the sponsor (or potential employer) can instantly access all available information for that project. A sample of available project information and the respective links to all documentations is presented in **Figure 4**. **Figure 5** provides an example of a Capstone project summary report presentation completed and submitted during the 2016-2017 academic year.
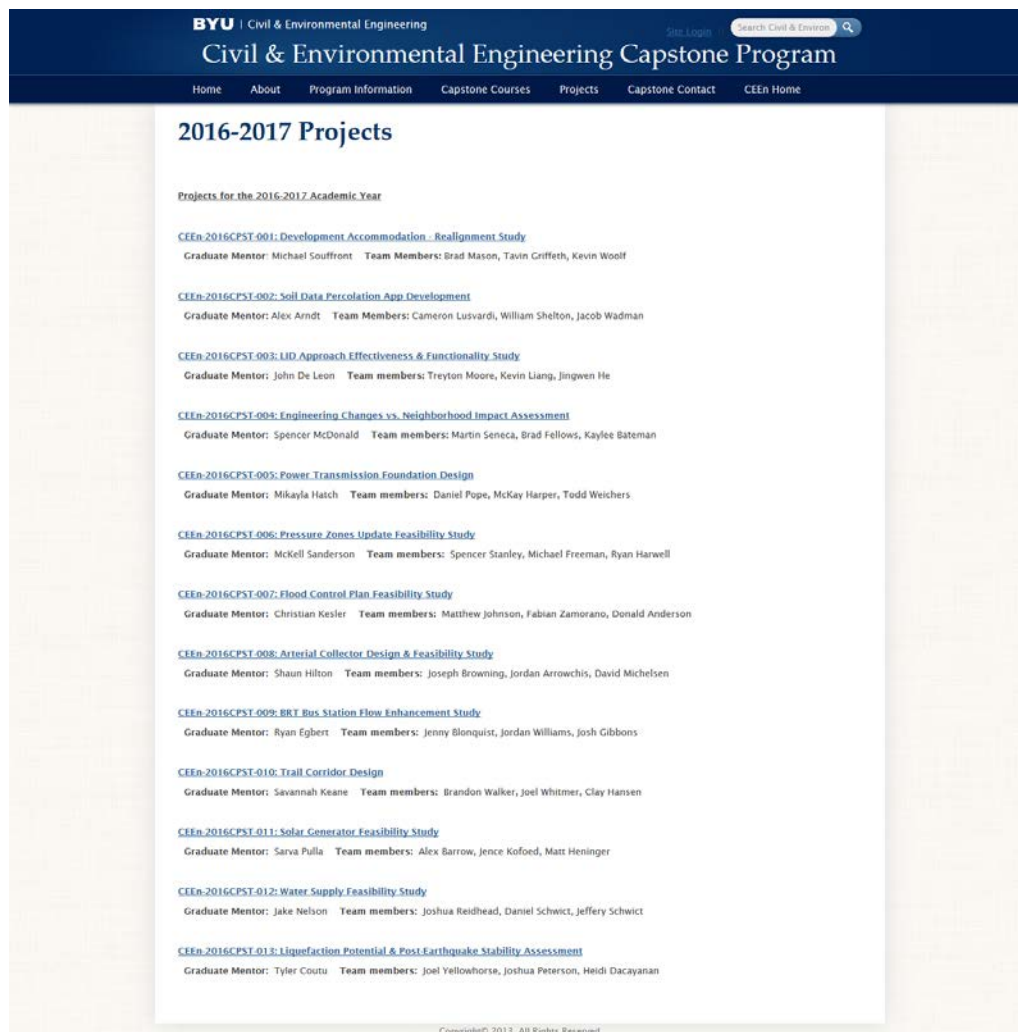
Figure 3   BYU CEEn's Capstone Website Showcasing Student Teams' 2016-2017 Project Work

Figure 4   Sample of Project Information Posted on the CEEn Capstone Website

Figure 5   Sample Capstone Project Summary Report Deliverable

12) Important Perspectives on Capstone Objectives

The old saying of "it is not what you say, but how you say it that matters" applies in marketing Capstone services. The challenge in convincing potential sponsors or customers to support a given Capstone program is often hinged on the following:

1) Helping potential sponsors understand why they want to support the Capstone Program.

2) What tangible and often financial benefits the sponsors will get in return for their support? Many sponsors do not recognize the potential tangible benefits that may result from a capstone project and view support of these projects as a goodwill or charitable contribution. They need to be educated about the project benefits.

While the most important objective for a Capstone Program is to provide a "real world" learning experience which graduating students can obtain before entering their respective work fields, many potential sponsors do not recognize that supporting the local Capstone Program will benefit their own financial bottom lines. From their perspective, the support they provide is only to help students prepare for the "real world" which may or may not be directly applicable to them.

A possible solution to this dilemma is to change the perspective from which potential sponsors see Capstone support. Instead of soliciting help from potential sponsors to support Capstone projects as a charitable cause in helping students prepare for the real world, Capstone personnel can work directly with sponsors to develop project ideas that will provide much greater financial incentives to the sponsors than what they contribute to the program. For example, to maintain competitiveness, sponsoring organizations are always looking for ways to cut costs, improve manufacturing or construction efficiency, improve product quality and reliability, etc. In order to demonstrate and implement novel ideas that can help improve a business's financial bottom line, a significant amount of investment and resources are often required. In such cases, Capstone projects can be utilized for proof-of-concepts to demonstrate the viability of a potential sponsors' innovative ideas through trade studies and/or a specific case study.

Investment support for the Capstone projects is often pennies on a dollar with respect to financial benefits resulting from a viability and feasibility study through one or more Capstone projects in comparison to having to invest much more by utilizing one's own staff, or hired consultants to perform the same tasks.

Helping customers or sponsors recognize potential beneficial resources for their businesses can open up win-win opportunities for both the sponsors and the corresponding Capstone Program. Our CEEn Capstone Program is in the process of negotiating an actual feasibility study program for a potential site development project with funding as well as support and collaboration from the sponsors' engineering firm. Similar approaches have been used regularly in actual engineering and government practices that evolved into large (i.e. multi-million dollars) projects. In fact, this is how many of the innovative cost-savings projects started – by casual communications between customers and vendors[3].

Most, if not all, of the soft-skills outlined above are beyond technical and engineering skills which students are familiar with through their college courses. These soft-skills are often impractical to teach in a classroom setting. Nevertheless, they are crucial to the success of each young professional's career growth and job security.

Although it is improbable to train the outgoing students on every aspect of all soft-skills, it is, nevertheless, important to help them experience and recognize some of these scenarios in a real-world project setting while in school. By so doing outgoing students can be prepared to adapt and account for the unexpected that inevitably take place regularly in any given project for which they are about to engage in their respective professional field of practice.

Lessons Learned

In its inauguration year of the enhanced Capstone Program, we successfully completed 13 projects and, developed/implemented a new website to host our project information, which assisted multiple students in gaining permanent employment by sharing their project works with their potential employers during their job interviews. Improvements to our Capstone Program and its online information sharing methodology are on-going. Samples of valuable lessons learned from our inauguration year to be applied for future project administration are listed below:

- Improve adaptability of Capstone schedule. Many potential Capstone projects do not coincide with the normal academic schedule (i.e. Fall and Winter Semesters). Fast track and long-term project schedule may be necessary in the future to accommodate sponsors' needs without over-stretching limited faculty and advisory resources.

- Provide greater professional advisement and encouragement access to student teams as they work through their project tasks to minimize project anxiety often felt by the students to accomplish project tasks that are outside of their individual comfort zones.

- Improve earlier access and uniformity to documentation templates as students are learning how to prepare professional quality documents and presentations that would help boost their confidence in actual work environments when they are asked to report their work in progress in a specific format and/or presentation style unique to their employer

- Enhance and improve marketing approaches to solicit future projects from existing and new potential project sponsors that would help sustain, as well as grow our Capstone Program

- Document processes and ideas that are proven to be effective in administering Capstone projects

- Improve and encourage better communications between student teams and their sponsors as well as both academic and professional advisors

- Clear communications and mutual understanding: When requirements and expectations along with the corresponding benefits toward their career potentials are explained in details to the students as they embarking on the Capstone journey, most, if not all, student teams will rise to the occasion in delivering high quality workmanship as demonstrated in our 2016-2017 Program. When students accept ownership and responsibility for their projects, the quality of work increases and the result is a win-win scenario for all involved in the program – this is known as inspired learning – a theme focused by the current BYU leadership.

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Wayne Y. Lee

B.S. Mathematics, B.S./M.S./Ph.D. Civil Engineering. Registered P.E. in WA and AZ. Director of BYU CEEn Capstone Program. Retired in June, 2016 as a Shock Physicist for projects supporting DOD, DOE, DOT, DHS, DTRA, NRC, and commercial programs. Principal, Vice President/Director of Engineering, Chief Engineer, Chief Technical Staff, and Research Consultant for MWECC, Raytheon, Nammo-Talley, Boeing, Applied Research Associates, Pacific Engineering, and Hercules Aerospace. Two US patents (2012, 2016), ten US patent-pending (2013-2016), and five international patent-pending (2015-2016). Specialized in shock physics research & application in conjunction with high fidelity modeling and simulations.

E. James Nelson

Dr. Nelson has taught surveying, GIS, hydrology, and hydrologic modeling courses at BYU for more than 20 years. Has led in developing experiential learning classes including a semester study abroad class in Latin America and the development of a capstone program that provides students real-world experience from private and public sponsored projects. Primary developer of the Watershed Modeling System adopted by the Federal Highways Administration for roadway drainage design and has taught short courses in more than 20 states and several countries worldwide. More recently he has worked with the National Weather Service's Office of Water Prediction in developing data management and visualization of the new National Water Model.

M. Brett Borup

M. Brett Borup, Associate Professor, Brigham Young University, Deparrtment of Civil and Environmental Engineering since 1987. Ph. D., Engineering, Clemson University;   M. S., Civil and Environmental Engineering, Utah State University; B. S., Environmental Resources Engineering, Humboldt State University. Capstone course instructor. Teaches and conducts research in water and wastewater unit process operation and design.