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A Holistic Approach to Civil Engineering Capstone Design

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Abstract

We present a holistic approach that culminates the senior design course as a unique opportunity/outcome for the civil engineering undergraduate program. The objectives are to deliver a capstone senior design that, in addition to meeting design educational requirements, (1) enhances the professional skills of the students, as necessary for them to thrive in their future careers, and (2) serves as a platform through which the undergraduate experience of all students in the program is enhanced. The approach involves complementary engagement of a technical advisor, a course instructor, a course facilitator, and an industry sponsor. The technical advisor ensures that the project synthesizes and applies technical knowledge (e.g., engineering design, software, analysis, prototyping, testing, project management, etc.) as taught in the sophomore and junior years. The course instructor is responsible for overall guidance, scheduling, assignments, team set-up and coordination, and assessment. The course facilitator incorporates specialty seminars, networking events, outreach, site visits, and career opportunities offered within the senior design course to the entire undergraduate program with the aim of enhancing students' professional skills and industry contacts. The industry sponsor provides the problem statement with design criteria and objectives and provides industry-specific guidance to solve the problem. Based on surveys, substantial department administration and faculty buy-in, this approach has proven to be highly beneficial to the students and department. Particularly, this holistic approach demonstrates that, in addition to meeting the program's overall goals, the capstone senior design could be used to cultivate an education environment that presents more internship and career possibilities to the students, enhances faculty mentoring, and encourages alumni engagement.

Introduction

Undergraduate engineering programs are expected to prepare students for the challenges of a professional career in their chosen field of engineering [1] [2]. In general, instruction leading up to capstone design is typically lecture and/or lab-based, which enhances the student's topical knowledge. The objective of senior design is to then apply this knowledge to improve the student's readiness for success post-graduation. As such, the capstone design course is the closest students get to experience challenges they might face as professionals with minimal adverse consequences [3] [4] [5]. The capstone design course presents a unique opportunity to bring faculty, students, and industry practitioners together [6]. The course also facilitates all stakeholders to define, address and solve industry-identified and challenging problems, while also matching individual interests [7] [8]. The evolution of stakeholder engagement through senior design [9] and its beneficial effects have been evaluated [10] [11] and beneficial effects of exposing students to diverse approaches for engineering design problem solving have also been stressed [12] [13].

The senior design projects in our civil engineering program have been predominantly industry sponsored for over two decades. Findings related to industry engagement and inclusion of requirements, such as sustainability, have been previously presented [14] [15] [16]. We aim to build upon our program particularities and industry relations to (1) increase the impact of our

capstone senior design, (2) present the opportunity for graduating students to enhance their professional and critical skills and field exposure, (3) provide all undergraduate students in the program with opportunities to participate in some of the activities, such as attending professional seminars and field visits, and (4) support broader alumni engagement.

In addition to benefiting the students, we aim at enhancing the collaboration between the faculty and industry professionals. By integrating all outreach activities of the department and ensuring that one activity contributes to another, as much as possible, we hoped to save time and resources while obtaining high student satisfaction and outcomes achievement. To meet the above objectives, we implemented changes to the delivery of our senior design course. The new framework allows for engaging alumni, guest speakers, field trips, and professional societies in a centralized holistic manner. Details regarding this integrated approach to senior design delivery are discussed below, along with the findings from surveys we conducted to understand student perceptions.

Delivery Format:

The delivery format designed as an academic year long experience was based on the identification of four major activities as essential to enhance the overall student experience. These include course instruction, technical design content, professional development, and industry support. The basic framework for an efficient and enhanced delivery of the capstone design, shown in Figure 1, was established based on preliminary discussions among the department chair, the associate chair for undergraduate studies, and the undergraduate academic advisor, followed by more extensive discussions with the department faculty. To enable this delivery format, four distinct roles for the course instructor, sponsor, technical advisor, and facilitator, were identified.
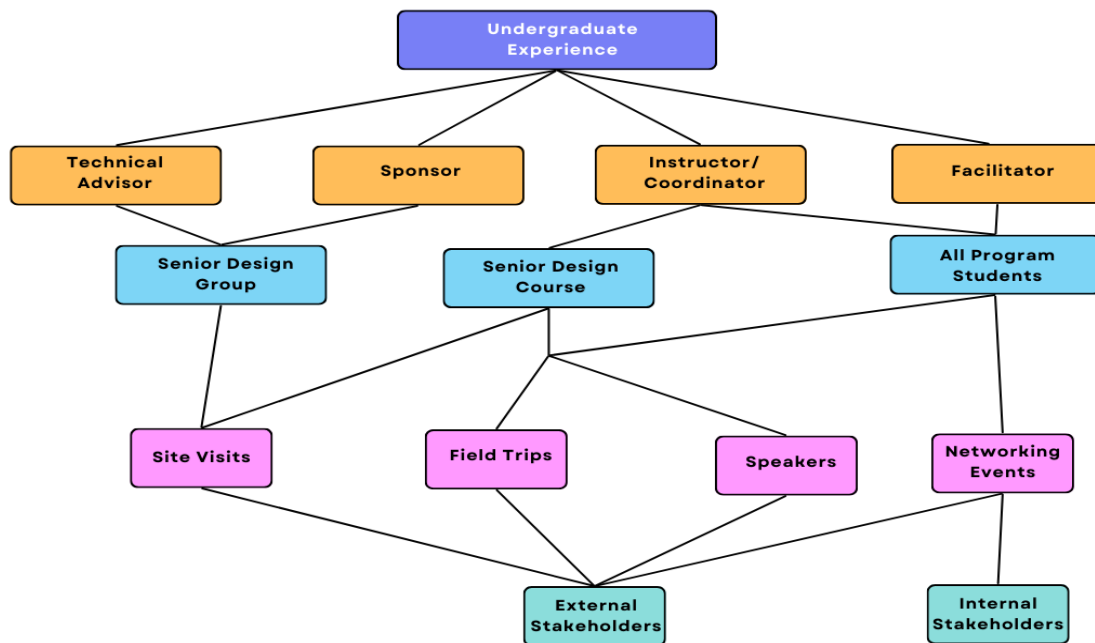

Figure 1 – Framework identifying responsibilities and activities of capstone senior design

The instructor provides overall guidance and vision for the course. They ensure maintenance of all requirements including meetings, site visits, seminar attendance, presentation schedules, curriculum requirements, etc. They manage team set up and project selection, assignments, course requirements and Canvas. The instructor is the primary contact with the Dean's Office on multidisciplinary projects. They are also responsible for ABET [17] assessment and overall course grading. Students meet the instructor twice a week during the scheduled class time.

The senior design advisor is the designated department primary contact for students with specific senior design project questions. They provide design and subject matter guidance and hold periodic meetings with student teams and sponsors. They attend and review presentations, posters, and reports. Students meet the senior design advisor nominally once every two weeks by appointment.

The senior design sponsor is responsible for providing the problem statement, project and site specifications, and industry specific guidance and viewpoint. In addition, the sponsor provides guidance on employability or professional skills, and feedback to the students on their reports and presentations and to the instructor on student performance and project progress. Students meet with the sponsor nominally once every two weeks by appointment.

The senior design facilitator coordinates outreach with external sponsors and project logistics. They maintain historical records and contact information for sponsors, projects, and outreach efforts to assist in generating undergraduate and graduate career prospects, including co-op, internship, and CPT opportunities. They also integrate seminars, guest speakers, networking, and social media outreach efforts within the undergraduate experience. This covers incorporating student engagement, such as site visits, student competitions, certifications, and student-led professional organizations. Students meet with the facilitator at least once a month during class time and informally several times, as the facilitator is also their academic advisor.

Thirteen projects were proposed by industry partners in AY 23-24. The department provided an equitable forum where all projects were presented to the students who signed up for the projects based on their interests and career goals. Project group sizes were limited to a maximum of four. The selected projects are presented in Table 1.

Table 1 - List of Projects and Sponsors

Project Title	Sponsor
107th Street Pier & Bobby Wagner Walk Reconstruction	Stantec
1300 Jefferson	Pegasus Partners LLC
ADA Upgrades at Woodhaven Station	Keller
Commercial Site Revitalization	Kimley-Horn
Commercial Structure	Structural Workshop
Higbee Beach Wildlife Management Area Restoration	WSP
Replacement of Existing Multi-Span Bridge	Thornton Tomasetti
Restoration of NJ Transit Hoboken Terminal	Hall Construction LLC
Washington Road over D&R Canal	WSP

At the end of each semester, in addition to other deliverables, students are expected to submit a final report and make a comprehensive presentation. The students will also create a poster at the end of second semester of senior design. This poster is presented at the University's Innovation Expo, where senior students across the institute showcase their capstone projects to the campus community and industry. The approach also provides junior and sophomore students early exposure to senior design, which is very beneficial [18].

Preliminary Survey

During the first week of the semester, all students enrolled in the senior design course received invitations to participate via email and in-class announcements. They were also surveyed to determine the type of seminars they wanted to attend based on their interests, goals, and needs.

Specifically, they were given the following choices and were permitted to select all that apply:
-Seminars about projects from industry professionals
-Seminars about career advice from industry professionals
-Seminars about additional technical support from a faculty member
-Seminars about the business side of engineering from an industry professional
-Seminars about steps to certifications/licenses
Please include any other interests you may have.

Of the 16 students who responded to the survey (44.4% response rate):
-16/16 stated they were interested in a seminar about projects from industry professionals.
-13/16 stated they were interested in a seminar about career advice from industry professionals.
-3/16 stated they were interested in additional technical support from a faculty member.
-9/16 stated they were interested in a seminar about the business side of engineering from an industry professional
-12/16 stated they were interested in a seminar about the steps to certifications and licenses.

These results were used to decide on seminar topics and identify speakers [19]. Based on our goals and student feedback, we invited two industry speakers in Fall 2023 and scheduled four industry speakers for Spring 2024. We organized two student field trips and two networking events. In addition, we also had eleven meetings with external industry representatives and local and state government offices from New York and New Jersey. We engaged these new contacts with the department, as well as individual students and student-run professional organizations.

Course Outcomes

At the conclusion of the fall semester, we requested all undergraduate students in the program to complete another survey to self-assess on several goals [20]. The survey, presented in Table 2, was emailed to the students and was also announced through the department's Canvas. The survey asked students to compare their perceptions of various factors after Fall 2023 to before Fall 2023. Given that the integrated outreach approach was implemented in Fall 2023, we hypothesize that the results are, at least partially, impacted by the new approach. The survey results are presented in Table 3.

Table 2 – Student Satisfaction Survey Questions

Number	Question
1	"I have developed a better industry network, compared to August 2023"
2	"I feel more confident that I developed professional skills necessary to enter the workforce, compared to August 2023. These include communication, teamwork, lifelong learning, and networking skills"
3	"I feel more knowledgeable about different career paths in my field of study, compared to August 2023"
4	"I have developed more connections with CEOE faculty, compared to August 2023"

Table 3 – Student Satisfaction Survey Results

Survey Question	Total Students (Program/ Senior Students)	Response Rate % (Program/ Senior Students)	Strongly Agree % (Program/ Senior Students)	Agree % (Program/ Senior Students)	Neutral % (Program/ Senior Students)	Disagree % (Program/ Senior Students)
1	70/22	29.8/51.1	35.7/45.4	50/45.5	12.8/9.0	1.4/0
2	70/22	29.8/51.1	35.7/45.4	54.8/54.5	10/0	0/0
3	70/22	29.8/51.1	28.5/50	60/40.9	10/4.5	1.4/0
4	70/22	29.8/51.1	32.8/63.6	45.7/31.8	18.5/4.5	2.85/0

On "I have developed a better industry network, compared to August 2023", 85.7% of students strongly agreed or agreed with the statement. The percentage of agreement was 91% if we consider only the senior students.

On "I feel more confident that I developed the professional skills necessary to enter the workforce, compared to August 2023", 90.5% of all students strongly agreed or agreed with the statement, as did 100% of the senior students.

On, "I feel more knowledgeable about different career paths in my field of study, compared to August 2023", 88.5% of all students and 90.9% of the senior students strongly agreed or agreed with the statement.

On, "I have developed more connections with CEOE faculty, compared to August 2023", 78.5% of all students and 95.4% of the senior students strongly agreed or agreed with the statement.

More notably, none of the senior students disagreed with any of the statements, and the overall student disagreement percentage on all questions is less than 3%. The findings demonstrate that the implemented framework of the capstone design course had a significant positive impact on all students, particularly senior students.

Similar trends were observed when we sought students' perceptions on their development of various professional skills (Table 4).

Table 4 – Survey Results on Improvement of Professional Skills

Assessed Professional Skill	Total Students (Program / Senior Students)	Response Rate % (Program/ Senior Students)	Strongly Agree % (Program/ Senior Students)	Agree % (Program/ Senior Students)	Neutral % (Program/ Senior Students)	Disagree % (Program/ Senior Students)
Communication	70/22	29.8/51.1	36.6/59.1	56.3/40.9	7/0	0/0
Teamwork	70/22	29.8/51.1	40.8/59.1	49.3/40.9	9.9/0	0/0
Lifelong Learning	70/22	29.8/51.1	40.8/54.5	43.7/40.9	14.1/4.5	1.4/0
Networking	70/22	29.8/51.1	38/50	47.9/45.5	12.7/4.5	1.4/0

On, "I have improved my professional communication, compared to August 2023" and "I have improved my professional teamwork, compared to August 2023", all senior students selected strongly agreed or agreed. Comparatively, 92.9% of all students selected strongly agreed or agreed when assessing their improvement in communication and 90.1% on teamwork. All remaining students selected neutral in this timeframe, with no students disagreeing.

On, "I have improved my lifelong learning, compared to August 2023", 95.4% of senior students selected strongly agreed or agreed that their lifelong learning skills have improved, and the remaining 4.5% selected neutral with no senior students disagreeing. Among all students, 84.5% strongly agreed or agreed with this statement.

On, "I have improved my networking, compared to August 2023", 95.5% of senior students strongly agreed or agreed that their networking skills have improved, and the remaining 4.5% selected neutral with no senior students disagreeing. Among all students, 85.9% strongly agreed or agreed with this statement.

In relation to our delivery of senior design, we identified at least nine companies that are currently offering internships to our students. Following each engagement event, we posted the details and photos on our department social media accounts. Given that 67.4% of the department's social media following is from the NYC metropolitan area, we hypothesize that this activity increased the department's reach locally and helped connect with additional industry partners.

The effectiveness of our framework was reflected in the attendance of our annual undergraduate networking event. For the inaugural event in 2023, 38 separate companies were invited and representatives from 29 companies attended the event. In 2024, 83 separate companies were invited with representatives from 71 companies attending the event.

We also have a significant increase in the number of industry speaker requests. In Fall 2023, we started with two industry speakers. However, our outreach efforts resulted in more volunteers for industry speaking engagements. This led to four speakers volunteering in Spring 2024, which we think is the maximum we can accommodate. Three additional speaker volunteers were deferred to Fall 2024. Nevertheless, these speakers will remain connected to the department in other ways, including attending the department-wide networking event, participating in our student-led professional societies' meetings, and providing contacts for internships, co-ops, careers, and scholarship opportunities. We shall note here that about 20% of our students participate in an industry co-op or internship on a regular basis.

Conclusions

Overall, the survey results show substantial student satisfaction with respect to their learning and professional goals and skills. The satisfaction is higher for senior students compared to other student cohorts. Industry engagement has improved substantially, as shown by the healthy growth in the attendance at events, internship and employment opportunities, and industry volunteers for speaking engagements. This can, at least partially, be attributed to the department's focus on integrating industry contacts and opportunities into the full undergraduate experience. As these students become alumni and enter the workforce, we contend that their desire to remain connected to the institute at the program level will be strong, thus allowing these initiatives to continue to develop and grow over time. The holistic planning of all external engagement activities of the department is shown to result in high student satisfaction and high levels of achievement on certain professional skills. The main organizational effort was in cataloging various activities of the department and developing an integrated awareness. This additional effort soon paid off with time savings that resulted from one activity feeding into another. To date, we engaged every potential external contact through one of the several avenues of student engagement depending on the topic and mutual interests.

Despite the advantages of our approach, it must be noted that we are a mid-size (with ~50 senior students and ~10 faculty) civil engineering program. Scaling our approach to significantly smaller or larger program sizes might require a different set up. For example, larger programs might require more facilitators to track the proportionately larger industry engagement. Similarly, smaller programs may require consolidation of the different roles.

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