2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #37614

Redesigning Senior Capstone Sequence with Multidisciplinary, Industry-Sponsored Projects

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Abstract

Capstone projects performed by engineering senior students in the last year of their studies are a constituent of the undergraduate curriculums and have a significant role in students' future careers. Currently, some, if not most, of these projects across the country are proposed by students and approved by program faculty members. As a result, the projects may not fulfill the requirements published by the Accreditation Board for Engineering and Technology (ABET) for the engineering technology baccalaureate-level programs: the capstone experience, ideally multidisciplinary in nature, must be project-based and include formal design, implementation, and test processes. Even if a project follows those guidelines, they may still not have the best experience for senior students who will be ready to apply for full-time jobs. One of the lacking experiences could be the possibility of working on real-world projects, which is currently happening in the industry. In addition, the nature of most of the projects in the industry is multidisciplinary, and they usually require teams of engineers from different disciplines to perform a project. This paper presents efforts to redesign the senior project processes to fulfill these requirements and provide students with the best possible experience in capstone projects. We will discuss that the results of the developed processes not only fulfill these two requirements but also end up with several other advantages for different parties. For students, the efforts help them experience challenging, up-to-date projects sponsored by the industry under industrial and faculty advisors, engage them in solving existing problems, familiarize them with all aspects of development with an industrial approach, and assist them in the hands-on learning process. The projects also allow students to gain experience in a real work environment and access to more industrial facilities. They also help students familiarize themselves with potential employers in their areas of interest. For industry, the efforts succor the companies fulfill their technical needs with additional dedicated resources and provide opportunities for professional development and education of their potential engineers for prospective employment. They also aid companies in receiving further advice from the faculty on more up-to-date designs and methods. For faculty, the processes help faculty get connected with industry, advise and collaborate on industry-supported projects, receive additional funding for projects, and publish potential scientific papers on new products, processes, and methods. The paper also includes project solicitation and proposal review processes, the engineering technology curriculum's capstone course structure, and the roles of different parties, such as the Industrial Advisory Board, faculty, and industry representatives, in the projects.

Introduction

A capstone design course is a major part of an engineering program. Students in the last year of their bachelor studies perform a team-based design project to show their ability to apply the knowledge obtained earlier to an engineering problem. This is important as students will face similar projects when they start working in the industry after graduation. In capstone experience, students are required to use engineering codes and standards and consider other constraints, including economic, environmental, ethical, health and safety, manufacturability, sustainability, and social and political thoughts in a problem. According to ABET, the capstone course is the primary course to fulfill criterion 4, which requires students to be ready for engineering practice based on the courses completed earlier. In addition, the capstone course also supports criterion 3, which requires students to show their ability to design a system, component, or process to solve a problem [1].

Significance of multidisciplinary aspects in the capstone experience

Multidisciplinary is one of the most important aspects of capstone experience [2-3]. Students from different majors can help each other to accomplish the project. Each student could learn about disciplines other than their own area, an essential aspect of the industry nowadays. This would also help students get motivated to work further on the project [4]. When looking at real-world projects in the industry, most include teams of staff from different disciplines. This is required for companies to be able to develop products, processes, or systems that combine various engineering aspects [5-6]. This fact can help students practice before getting into the real-world industry.

Multidisciplinary capstone projects focus on effective team working and product development that require people from different disciplines [7]. It was shown that this aspect of the team helped improve the quality of the projects [8]. This will also help students practice essential elements of education, such as critical thinking and problem-solving, before graduation. In another effort, it was discussed that solutions to challenging problems could be found by forming multidisciplinary teams and applying knowledge from various disciplines [9]. Several other people have discussed multidisciplinary projects [10-13]. This paper presents a unique approach to redesigning capstone projects. The multidisciplinary aspect is one of the components of the process.

Significance of collaboration in teams in the capstone experience

As discussed in the previous section, multidisciplinary projects are common, particularly in an industry where graduates from different disciplines will work together. This requires engineers and other staff in a firm to collaborate on a team. Each team member could utilize their knowledge in a more focused fashion to contribute to the project. This will help improve individual performance, and as a result, a higher quality of the project will be achieved [14]. In addition, this collaboration will help them improve their learning performance [15]. Universities can simulate what is happening in the industry by forming teams of students in capstone projects.

The performance of the projects could be evaluated for teamwork effectiveness. This is important for engineering schools accredited by the ABET organization. ABET general criteria require engineering schools to document that their students have gained skillsets to function on a team. Student outcome 5 within ABET criterion 3 is about teamwork and requires engineering students 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 [16]. The author of this paper, with several years of industrial experience, verifies that this ABET outcome conforms with what the industry requires. The industry forms teams for effective collaboration among their members to provide useful products and services. As a result, capstone projects at engineering schools need to be designed to create an environment for students to obtain this skill set.

Significance of collaboration with industry in the capstone experience

Collaboration with industry has become more important in the last few years. First, the industry is motivated to work with the university to access new technology findings and enhance their innovation [17]. This collaboration ends up improving business value and being able to compete with other companies [18]. On the other hand, collaboration with industry helps students to gain invaluable technical and professional experience with real-world projects and advanced technologies before they graduate and work on similar projects [19]. Although this is a worthy goal for both sides, there are always challenges to achieving this goal. It is known that there is a gap between industry and academia, and collaboration between these two sectors can help link the sectors with each other. To improve the student experience at the university and prepare them for the industry, industry knowledge can be adapted by the university to be used by students at the university [20]. In addition, collaboration with industry will help get scientific practices in academia close to production practices.

History of the capstone experience

Most of the engineering technology programs at the institution that the author of this paper previously worked for are in the same department. Those programs include mechanical engineering technology, electrical engineering technology, computer engineering technology, and mechatronics. This is an advantage of this department as the instructors from different disciplines can sit and create multidisciplinary or even interdisciplinary subjects. The programs focus on hands-on experiences in the courses. The most important courses of these programs are within a senior project sequence, which is designed based on a two-semester experience. A one-credit course, Senior Seminar and Design, is offered in the fall, and a three-credit course, Senior Technical Project is offered in the spring of the senior year. All engineering technology students are required to take these two courses to graduate.

Before implementing the new model of capstone sequence, two major topics were discussed by a single instructor in Senior Seminar and Design course in the fall. First, students were introduced to the basic information a senior student might need, including library research techniques, project planning and management (Gantt Chart), resume and cover letter, interviewing and job search techniques, professional licensure and registration, and professional ethics. This part of the course took most of the one-hour weekly lecture time. Second, students were supposed to form teams of 3-4 students and propose a senior project idea. This part of the work was mainly performed outside of class time.

Teams were required to submit one-page proposals at the end of the semester, which was used as a seed for the project in the Senior Technical Project Course in the spring. All senior project proposals were based on the student's ideas. This was the first drawback of the capstone sequence, as those ideas were not monitored to follow the recommended program and ABET guidelines. No guidelines were available for students to follow when creating the project ideas. The subjects of the projects sometimes did not follow the program concentrations. Furthermore, the project ideas were focused only on a single discipline, while ABET recommended multidisciplinary topics. In addition, there was not much time for the students in the one-credit course to perform engineering work on the projects.

The spring's three-credit Senior Technical Project included lecture and lab sections. A primary instructor for the lecture section of the course administered the course. If students had any questions about the assignments, this instructor would answer those questions. On the other side of the course were multiple lab sections where an instructor was assigned as an advisor to each section. There was a cap of 10 students enrolled in each lab section. These instructors were to advise the students throughout the spring semester. The first issue in this course was the time commitment. The first two weeks of the semester were used to kick off the projects by the teams. In addition, the last two weeks of the semester were used for dry-run presentations by students. As a result, only 11 weeks were left for any engineering work on senior projects. Because no engineering work was done in the fall due to time constraints, all work, including calculation, simulation, design, fabrication, testing, and writing, needed to be performed in these remaining weeks. The project’s results showed that the work's quality could have been more impressive.

Faculty involvement and expectation seemed to be inconsistent across the course. Some advisors met weekly and required a significant report and presentation at the end of the semester. In contrast, some others met only a few times throughout the semester and had minimal expectations from students. Another issue was that students recorded a 10-15 minute presentation and submitted it to be reviewed by the instructors. The advantage of this method was that 2-3 instructors were assigned to evaluate the recorded presentation ending up with a more consistent review process; however, there were no interactions between students and evaluators. The evaluators left feedback for the students on the course management system, but students did not get a chance to see the comments because it was already the end of the semester. The evaluators were also unable to ask questions to be answered by the students. This was vital in the review process, where the evaluators needed to ask questions in a live meeting with students. Despite the facts mentioned above, there were faculty-sponsored projects that ended up with great results and publication [21-22].

Another issue was that some students arranged to graduate in the fall. This required the program to offer the Senior Technical Project course in the fall, usually offered in the spring. Those students took both courses in parallel, while the idea was to have a sequence of the courses. Some other students needed to be made aware that they needed to take the two courses back-to-back in the fall and spring to allow them to work on the same project with the same team. In addition, it was felt that ABET guidelines needed to be thoroughly followed in the senior capstone sequence. ABET program criteria for baccalaureate-level programs imply that the capstone experience, ideally multidisciplinary in nature, must be project-based and include formal design, implementation, and test processes.

Redesign of the capstone experience

To address the concerns listed above, the capstone sequence was redesigned by the author of this paper, who was the instructor of the capstone sequence courses at the previous institution. He held the department chair role, which was beneficial during the redesign process, where more resources needed to be used in the capstone sequence. More improvement, such as industry involvement than a resolution to the concerns listed above, was developed during the redesign of the capstone sequence. The following sections discuss the changes and new features in the courses.

Capstone project process

Capstone sequence requirements were revisited to address the concerns above. The first issue was the time commitment. The idea was to combine the two semesters to accommodate more time for engineering work. First, the one-credit Senior Seminar and Design course in the fall was not changeable due to constraints in the total number of required credits in the programs; however, the structure and content of the course were modified to make more room for advisement and engineering work in the fall. The one-hour lecture remained the same as before, but some of the assignments for the basic information offered in the course were changed to be conducted by students on their own. This reduced workload made some room for engineering work in the projects.

Planning and preparation for the senior capstone sequence started in the spring before the year when the courses were conducted. It included the discussion with the faculty and industry for involvement. A Capstone project proposal form was shared with the faculty and contacts in the industry. Several calls and meetings were held with the sponsors to consolidate the proposals aligned with the requirements defined in this document. A review was performed on each proposal, and revisions were requested.

Academic advisors were assigned to the projects per their expertise and interests. Additional resources, including equipment from the program, Industrial Advisory Board (IAB) involvement, Instructional Support Assistant (ISA) involvement, or any other support required from the program, were added to the proposals. Complete proposals were shared with all senior students in four majors. The idea was to assign students to the projects and subjects they would work on after graduation. Each student was requested to sign up for three projects of interest in priority order. This information was compiled, and students were assigned to the projects based on their interests, their capabilities in the subject, and the project requirements.

Final projects and students, academic advisor, and industrial advisor names were communicated with each team at the end of the spring semester. A kickoff meeting was held in the first week of the fall. During the kickoff meeting, students were assigned to prepare a Gantt Chart per the description from the sponsor, a detailed schedule, and a working budget for their projects within a week. The advisors reviewed them for any revisions. Note that the new design of the capstone project allows the teams to perform the projects annually, starting in the fall and ending spring of the academic year. The team held weekly meetings to ensure the quality and being on track. Instead of requesting students record videos of their presentations and submit them for review, a poster presentation conference was held at the end of the fall, and an oral PowerPoint presentation conference with parallel concentration sessions at the end of spring. In both cases, several people, including industry representatives, industrial advisors, IAB members, and academic advisors, were invited to review the projects and submit their grades and feedback online. The feedback was then shared with the teams.

Capstone project requirements

In addition to the existing major requirements of Capstone projects, a few more requirements were added to the new model of the Capstone experience to address the concerns listed above. First, two project types were proposed instead of using student ideas in the projects, including industry-sponsored and faculty-sponsored projects. The program also considered if students solicited an industry-sponsored project through their own connections or discussed a project with a faculty member to be considered a faculty-sponsored project, as long as the projects meet the requirements. The projects needed to be interesting, relevant, challenging, and up-to-date. Novel and multidisciplinary projects and the ones attending national or regional design competitions were encouraged. Industry-sponsored projects needed to follow current industry practices. The project subjects are also required to be relevant to the major elements of the programs. A focus on the program concentrations, including smart energy, manufacturing, industrial automation, quality, design, and microsystems, was preferred. The project creator must provide project proposals, including full scope, budget, and schedule.

In addition to the specific requirements listed above, the projects needed to include a relationship with fundamental engineering aspects of engineering technology course work, original contribution compared with researched existing solutions, or implementation of existing solutions in novel ways, be based on solving a real-world problem, include a realistic, practical solution, and design concept, have a useful design, have a technical impact on society, and include implementation and testing or verification. Software development was considered as implementation.

In addition, all students in the programs were notified that the two Capstone sequence courses would no longer be offered in parallel in the fall. Students who arranged to graduate in the fall needed to take the two courses in the academic year before that fall. Also, they were reminded that the senior Capstone courses were required to be taken back-to-back in the same academic year, allowing students to work on the same project within the same team.

Industry sponsorship

The Capstone project redesign allowed this paper's author to communicate with the local industry and solicit real-world projects. The companies showed they were happy to work with the academia if they could fulfill their needs. There were several benefits to all three parties, including companies, students, and faculty members involved in the projects. Here are a few major benefits:

- To help the industry fulfill its technical needs with additional dedicated resources and provide opportunities for professional development and education of potential engineers for prospective employment.

- To help companies receive additional advice from faculty on more up-to-date designs and methods.

- To help students experience real-world, multidisciplinary industry-sponsored projects, engage them in solving existing problems, familiarize them with all aspects of development with an industrial approach, and help them in hands-on learning.

- To provide students with an opportunity to gain experience in a real work environment, access to more facilities, and help students familiarize themselves with potential employers in their areas of interest.

- To help faculty connect with the industry, advise and collaborate on industry-supported projects, receive additional funding, and publish potential scientific papers.

- To help faculty publish contributions on new products and methods and acquire additional funding for further development.

Project proposals addressing the requirements defined above, breakdown of budget (materials, equipment, etc.), company's advisor, project schedule, breakdown of activities required, facilities required, number of students needed from each major, and other information were prepared by the companies and submitted to the programs for consideration. The companies fully sponsored projects financially (if a cost was involved) and by advising. Most of the proposals received by the program had multidisciplinary topics because of the nature of the industry work. As a result, students from different majors were assigned to those projects. The companies' representatives were passionate about meeting weekly with the students and the academic advisor to ensure the project's completion. In addition, IAB members played a significant role in proposing the projects, connecting with other companies, and contributing to the existing projects, such as holding crash courses for certain students.

Comparison between the old and new styles of capstone sequence

As mentioned above, the new capstone sequence significantly differs from the old one. The changes were made to target specific objectives. Two major objectives when redesigning the sequence were an ultimate student experience and ABET requirements satisfaction. To reach the first goal, an attempt was made to answer a critical question, "why do students pay a lot to study in this major?" Although this question seems simple, answering it may lead us to achieve the goal. Of course, a prospective student's answer is to get ready for the industry after graduation. In the old capstone sequence, students created their own idea without considering the requirements. As a result, they did not gain enough design and hands-on experience through those projects. To support the second goal, ABET requirements for the engineering technology programs needed to be reviewed in detail to find the missing parts in the old sequence. The ABET has a clear capstone experience statement on the program criteria for mechanical engineering technology baccalaureate level programs: "The capstone experience, ideally multidisciplinary in nature, must be project-based and include formal design, implementation, and test processes."

By creating projects sponsored by the industry, both objectives are achieved. It is known that the industry only gets involved with academia on projects if they feel rewarded. They always want to include the implementation and testing in their projects; without that, there is no support on whether a design works. Of course, the industry-sponsored projects still need to fulfill the requirements discussed earlier. Table 1 compares the critical elements of the old and new capstone experiences.

Table 1: A comparison between the critical elements of the old and new capstone experiences.

Criterion	**Old Capstone Sequence**	**New Capstone Sequence**
Idea creation	Primarily based on student ideas.	Based on real-world problems.
Relevant and up-to-date ideas	Projects randomly followed these criteria.	Projects need to follow these two criteria.
Original contribution	The contributions were mostly from the existing products.	The contributions need to be original. Students need to add some novel contributions to the solution.
Engineering analysis	This part was sometimes missing, or students needed to perform it properly.	An FEA analysis or at least proper hand calculation is required.
Implementation	Depending on the project, it was or was not included.	All projects are required to retain this step.
Testing	This part was missing most of the time. It was thought that the implementation was enough.	All projects are required to include this step.
Team-based	Most of the time was team-based, but sometimes, only one student was in the project.	Team-based as required.
Multidisciplinary	Most of the time, the projects focused only on a single discipline.	Most projects are multidisciplinary, as the industry usually works on projects requiring engineers from different disciplines.
Project-based	The sequence was project-based only in the spring.	The sequence is project-based in the fall and spring.
Formal presentation	Students recorded a video and shared its link with a few faculty to grade. There were no interactions between the instructors and the students.	Students are required to present orally in parallel sessions at the end of the fall and in a poster session at the end of spring. Several people from industry and academia were invited to act as a reviewer.
Top project recognition	No.	At the end of the poster presentation in the spring, the top three projects were recognized.
Reporting	Students were required to submit a report but not on a standard template.	Students are required to submit their reports based on the provided rubrics.
Sponsorship	Funded by students.	Funded by industry or faculty.

Table 1: A comparison between the critical elements of the old and new capstone experiences. (continued)

Criterion	**Old Capstone Sequence**	**New Capstone Sequence**
Attending competitions	No incentives.	Some faculty- or industry-sponsored projects encourage attendance.
Current industry practices	Not followed.	Following.
Focus on program concentrations	Rarely.	Some projects focus.
Proposals	There were no proposals on a standard form. As a result, the expectations on different projects were not the same.	All projects are proposed on the same template, and a revision is requested if the information needs to be included.
Rigorousness	Projects were rarely rigorous.	All proposals are reviewed beforehand to ensure the same level of rigor.
Schedule	Only spring was used to perform the project. Students were allowed to take the two courses in the capstone sequence in parallel to complete their projects.	All weeks of fall and spring are used to perform the projects. Students must take the two courses in the capstone sequence in the fall and spring. Students who anticipate late or early graduation could enroll in the sequence the year before they graduate in the fall.
Gantt Chart	Students created a Gantt chart, but it was not tracked during the project.	A detailed Gantt chart is created by students based on the initial timeline/activity proposed and approved by the sponsor. The Gantt chart is tracked every week.
Meetings	Meetings were requested by students when needed.	Weekly meetings are conducted.
Number of projects per faculty (course section)	10 or more students, sometimes ending up with four projects.	4-6 students in two projects. This allows greater time dedication by the advisors.
Fall/spring activities	The course in the fall included topics for skill development; only a one-paragraph project idea and a rough Gantt chart with a slight grade point were included. The spring was for the design and possible implementation	While the fall course consists of skills development topics, it also contains the formal design and a portion of the implementation. The spring is used to complete the implementation and testing and present the results.

Table 1: A comparison between the critical elements of the old and new capstone experiences. (continued)

Criterion	Old Capstone Sequence	New Capstone Sequence
Idea generation time	The ideas were generated by the end of the fall.	The ideas are generated by the end of spring before the project kickoff in the fall.
Project effectiveness	The project didn't start until the spring. The first two weeks of the spring were more warm-up, and the last two weeks of the spring were for presentation practice. After that, there was only so much time left to complete an actual project.	All students and advisors are assigned by the end of spring before the kickoff meeting in the first week of fall. Two full semesters are used to complete a rigorous project.
Literature review	A literature or technology review was performed only upon request by the advisor.	A literature or technology review is essential to the projects and is performed in the fall.
Incentives	No.	Some companies paid incentives to students to improve the project's success rate.

Description of selected capstone projects

More than thirty different multidisciplinary senior projects were received from the industry and performed over two years (Fall 2021 to Spring 2023) at the author's previous institution. The projects were designed to be conducted through a two-semester senior project sequence. The fall semester was focused more on the engineering analysis, design, and part of the implementation, while the spring semester was used to complete the implementation and report the results. The focus of the projects was on the project ideas where students had an opportunity to work on real-world problems. A call was sent to local companies through the author's industry connections to fulfill this requirement. The idea was to provide senior projects to prepare students for the industry. While the students were assigned to the projects primarily based on their interests, other factors like the project location and skill requirements were considered. Each team of students was advised by at least an industrial advisor from the company and a faculty advisor. A brief description of three selected projects is given in this section. The name and technical details of some of the projects are not provided here due to confidentiality.

Project 1: Automated Fanuc Robot Weld Cell

HDM Hydraulics, Tonawanda, NY is a custom manufacturer of welded body hydraulic rods and telescopic cylinders servicing the mobile industry. The company aimed to replace a worker with an autonomous robot cell that loads three parts into a welding lathe and then takes the welded parts to a serial number stamper. Four senior mechanical engineering technology and mechatronics students worked with the company to complete the project at the author's institution. The project team was asked to develop a cell that automatically manufactures hydraulic cylinders. Students performed all project steps under the advisement of the company's representative, including the process design, the mechanical design of two gripper claw mounts and hooks for the robot and part cart with several tray inserts, and the programming of the Fanuc robot, and designing and wiring PLCs. All equipment in this project, including a drawer, lathe machine, Fanuc robot, stamper, and other accessories (Figure 1), were connected through PLCs. The equipment was shipped to the institution's site to be completed there over a year.

After completing the project, the developed cell and its equipment were shipped back to the company's site, and the parts were reassembled within a few days. At the company's site, there was a part loading station where enough parts for an eight-hour shift could be loaded. Afterward, the worker could leave the area, and the process would run unattended for the entire shift. A user interface was programmed so a worker could stop and start certain functions. After the parts were in the load station shelves, the robot arm extended and grabbed the three parts, and moved them to the weld lathe. An automated welder connected to the lathe welded the three pieces together. Next, the robot picked up the welded part and moved it to a pin stamper to print a serial number on the part. Upon completing this step, the robot picked up the part and moved it back to another tray in the drawer. While students gained invaluable experience performing this project, it had several advantages to the sponsor, including weld quality improvement, cost reduction, manufacturing rate improvement, etc.

Figure 1: Equipment used in Project 1, including a drawer, lathe machine, Fanuc robot, stamper, and other accessories.

Project 2: Development of a biogas digester

A company from New York City proposed this project. A team of students was asked to design, build and test a biogas digester used to produce methane gas from cow manure on farms using the anaerobic digestion process. The digested manure was also an excellent fertilizer to be used on farms. It is known that dairy cows and their manure produce greenhouse gas emissions contributing to climate change. The digester was also equipped with electronics and was able to measure and record specific process parameters using sensors and a data acquisition card (DAQ). The sensors measured the pressure, temperature, and pH level in the digester, the gas pressure in the storage tank, the gas flow, and ambient temperature. The project had not only a business justification but was also considered a sustainable project. Four senior students designed and built four major components of the system, including the digester tank, biogas scrubber, gas storage tank, water storage tank, and their accessories (Figure 3). The project was also presented at the 2022 Allegany County Collegiate Startup Competition and won the grand prize.

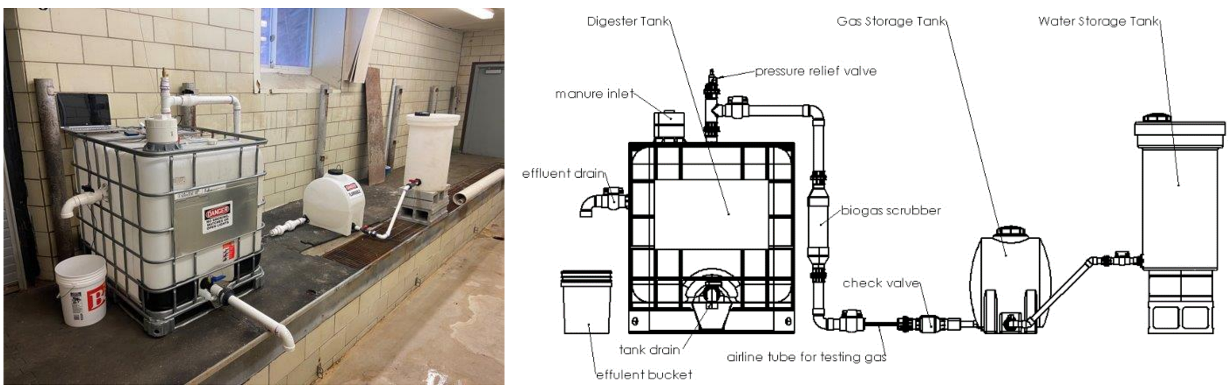

Figure 2: Biogas digester in Project 2.

Project 3: Drag Finisher

Cross Product Design, Buffalo, NY is a custom design and fabrication company that provides additive manufacturing and CNC machining services to other manufacturers. Four mechanical and computer engineering technology students were assigned to the project to design, build, and test a drag finisher with an Arduino touch-based GUI (Graphical User Interface). The drag finisher is an automated mass-finishing device that smoothens the outer surface of 3D-printed parts by mechanical abrasion. The students performed mechanical and electrical hardware designs and programmed Arduino. They designed and built a controller running through a touchscreen pad to adjust the speed/cycle of a drag finisher. They developed a circuit of electromechanical devices (e.g., motors).

Furthermore, the students programmed an Arduino microcontroller with a touch-based input device and created a basic GUI controlling each device. They also utilized Arduino programming to control a Motor Mega board. Since the control features needed to be interfaced with a touchscreen pad, they replaced the Arduino Nano with Arduino Uno to get an Arduino Mega 2560 during the design process. The GUI part was initially programmed and simulated using the Tinker CAD application. Once completed, they transferred it to the Arduino Board to run through the touchscreen pad. Using the GUI installed on the touchscreen pad, they could control the motor features such as speed and cycle by selecting options from the touchscreen pad and sending signals to the motor through the ports. In addition, the students used a 3D printer to print the body and casing for the drag finisher. This was a multidisciplinary project where the mechanical engineering technology student designed and fabricated the parts while the computer engineering technology students performed the rest of the work. The prototype was tested successfully and showed satisfactory results. Figure 4 shows the design and prototype of the drag finisher.

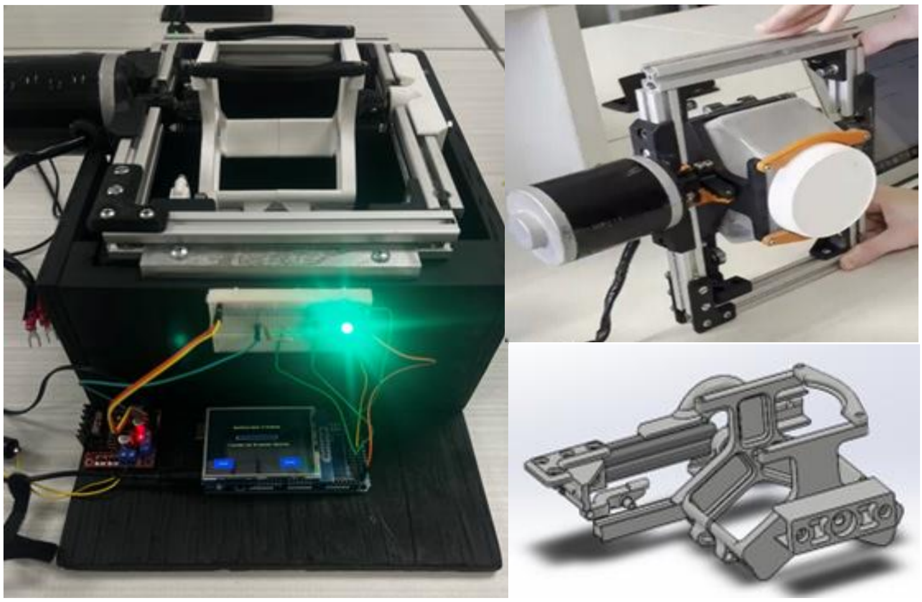

Figure 3: Design and prototype of the drag finisher developed in Project 3.

Student presentation for evaluation

Students are evaluated on their individual and teamwork in both capstone courses. In the fall course, students are assessed individually on assignments such as ethics, resume writing, and mock interview. A significant portion of the individual assessment is student performance. It reflects how each student participates in the team and meetings and submits their assignments on time. A major teamwork assignment in the fall course is an oral presentation. Several sessions are held in parallel. Students in each team need to present their preliminary results to the selected reviewers, who evaluate their technical work and presentation skills. There will be 15-min time at the end of the presentations when the reviewers can ask questions. Figure 4 shows a few photos of past oral presentations. There is no project report assignment in the fall.

Students in the spring are evaluated based on three assignments. Like the fall semester, they are assessed by industrial and academic advisors on their performance. The students also need to submit a technical report that is evaluated carefully by both academic and industrial advisors. The last position of evaluation is poster presentation. They need to present a poster at a two-hour poster event at the end of the spring. Several industrial, IAB, and faculty members visit the students' posters and review their work. A user-friendly Google form allows the reviewers to evaluate each project and its students right after seeing the poster. The results will be distributed to the advisors after the event. There will be another Google form that the reviewers use to pick their top three projects. The results on this form are compiled right after the event, and the top three projects will be announced and recognized with a certificate and prize. Figure 5 shows photos of the past poster presentation event.

Figure 4: Photos of past oral presentations

Figure 5: Photos of past poster presentation event

Feedback on experiences

This course was the first time offered in the new form. The old sequence was taught for years without any changes. It was known to everyone that this senior project redesign was overdue at such a reputable institution. When the new capstone project kicked off, the outcomes were unknown to some students and faculty. This caused some concerns about the results. However, because the shortcomings had been analyzed carefully in the old sequence, the outcomes were supposed to be promising. The most promising part was that most of the projects were completed ahead of time due to commitments from all parties.

Sponsor's perspectives

The companies had two different reasons for participating in this program. Some companies needed help from great students that got advice from up-to-date faculty members. They hoped that the teams could help them receive the results at a more reasonable cost. They knew the suppliers would charge them significantly when the project was quoted as a turnkey. The students from different disciplines could work under faculty members' advisement and the company's supervision to perform a custom project. The second group of companies hoped to train students through senior projects. They spend a tremendous amount of time scheduling weekly meetings with students and reviewing technical information that is impossible without someone working in the industry. They happily provided the students with this information with the hope that the students accept their offer to join their company after graduation.

In several cases happened that companies offer a job much ahead of time before they graduate. It is common in the industry for companies to train junior engineers professionally over a few months. By participating in the senior project program, the companies save time and costs in preparing a junior engineer for the work. It must be noted that not all students received such offers. In addition to the technical knowledge, the companies were seeking students with other soft skills such as leadership, communication, writing, attitude, etc. Weekly discussion with the students was an excellent opportunity for the company representatives to monitor the students and find their appropriate hire while training them in advance.

Instructor's and institution's perspectives

The faculty had been struggling with the issues that they dealt with the senior projects over the years. This new opportunity was outstanding for the faculty. The management and faculty were sure about the positive impact of the redesign on the retention rate. They learned at different events that the prospective students and their families were looking for programs that guarantee the student's success after graduation. In addition, the faculty hoped to advise students on more rigorous projects in which the industry is involved. They also seek opportunities for potential publication, such as scientific papers or patents that resulted from the projects' results. Some faculty hoped to connect with the companies and seek additional funding for the projects down the road.

On the other hand, making significant changes required much preparation from the institution and faculty logistically and timely. Some companies needed space at the institution site for the students to work on their projects. Some other companies required the company to sign NDA on their work, while others required the institution to open an account where they could deposit some refundable funds. This was a massive change from the institution's perspective. The faculty was concerned about the workload the new capstone sequence would cause due to more commitment. The faculty needed to meet weekly to ensure that the projects were on track. Considering the faculty's busy time, it put much workload on them. However, the same amount of time expectation was achieved with some changes in the workload and the course enrollment cap lowered.

Student's perspectives

Like the faculty situation, students also had positive and negative concerns about the new capstone sequence. First, there were clear signs that most students took advantage of this opportunity and tried accommodating themselves to the new design. They were willing to work hard even within a one-credit course in the fall since they were close to graduation and needed real-world experience before graduating. The author of this paper, who was the instructor of the record of the capstone sequence, reviewed the advantages of the industry-sponsored projects. So, the students knew some companies were identifying the selected students for hire. This motivated students to work hard and leverage their skills on the projects. Furthermore, as discussed in the next section, students were informed that they must present in front of industrial and academic evaluators at the end of both semesters. This helped students further to get prepare for the final presentation.

Students taking the new course sequence were provided with an opportunity to evaluate the course. They were asked to give feedback on two critical questions that would be helpful to the instructor as the information is used to improve the course structure in the following years. Table 2 presents the most critical comments that the students provided. The feedback on the first question indicates that the students were satisfied with the new design and the level of instruction. There were great comments in response to the second question that helped the instructor to adjust some areas, and they all were doable.

Impact on ABET student learning outcomes

As discussed earlier, the capstone sequence for engineering technology programs at the author's institution consists of two courses in the fall and spring of the senior year. ABET states that the engineering technology program must have documented student outcomes with an established and effective process. There are five student outcomes for the engineering technology baccalaureate degree programs set by ABET. Unlike some universities, the engineering technology programs at the author's university use all courses in each program to assess the five outcomes.

The capstone sequence is the most appropriate course for a summative assessment of a student's ability to perform engineering design. Although all five outcomes could be assessed with the culminating capstone courses, the program selected student outcome 5 to assess the two capstone courses. The outcome states "an ability to function effectively as a member as well as a leader on technical teams." The program objective supported by this assessment states "student can function professionally and with ethical responsibility as an individual and on multidisciplinary teams."

Table 2 – Feedback from Students on the Capstone Course

What are the major strengths of the instructor and course?
• It is excellent that the projects are connected to the industry. • Activities in class varied to keep it different than the past. • It is the first year of the senior seminar course in this format and is suitable for what it is. • Great opportunity to use open class time to gauge project progress and ask questions. • The instructor has a large number of resources to help senior project groups. • The instructor has knowledge and experience with engineering topics. • The instructor is always willing to help. • The instructor knows how to run the class well. • The instructor sets students up for success. • The instructor is able to keep on schedule.
In what ways can this instructor improve the course?
• Figure out the student's schedules before scheduling meetings. • As this is the first year of the new senior projects, some students are unsure what will happen at the end of the projects. • The multidisciplinary subjects of the senior projects seem to be more mechanical engineering based than electrical or computer engineering. • This fall class should be a 3-credit class, not a 1-credit one. • Get more professors involved in senior projects. • Consider additional topics or guest speakers, even within the department, to share experiences and possibly answer questions. • Give alerts to due dates. • Spend more time on the skills like interviews

The first course in the fall was assessed based on the final poster presentation. Students worked in teams and presented their posters in a poster event where over 40 reviewers from the industry, IAB (industrial advisory board), and faculty evaluated their work. The instructor received over 250 evaluations from the reviewers using an online Google form. The results showed that 95% of the students received grades 70% or higher in this assignment. Students were prepared to provide professional presentations. Therefore, the student outcome was evaluated with no deficiencies to report.

The second course in the spring was assessed based on the final project report, where the final results of the projects are presented. Students worked in teams and wrote a technical report on the results comprising the information from ideation to design, fabrication, and testing. Industrial and academic advisors carefully evaluated the reports. The results indicated that 100% of the students in the course received grades 70% or higher in this assignment. The students showed excellent progress on the projects in the spring, which concluded the projects. It was discussed that it was not a surprise that all students functioned effectively in this assessment, as all advisors were thankful for their hard work. As a result, the student outcome was achieved.

Another ABET requirement of the capstone experience on the program criteria for mechanical engineering technology baccalaureate level programs states: “The capstone experience, ideally multidisciplinary in nature, must be project-based and include formal design, implementation, and test processes.” There are five terms in this statement, including “multidisciplinary,” “formal design,” “implementation,” and “test,” that need to be added to the capstone requirements at the program level. All these five terms were set as the senior capstone project requirements, as discussed earlier.

Conclusions

Capstone design course is a major part of engineering programs. Students in the last year of their bachelor studies perform a team-based design project to show their ability to apply the knowledge obtained earlier to an engineering problem. This is important as students will face similar projects when they start working in the industry after graduation. Most capstone projects nationwide are designed based on the student’s ideas. As a result, the projects may not be rigorous enough for the best student experience or fulfill the ABET requirements. One of the lacking experiences could be the possibility of working on real-world projects, which is currently happening in the industry. In addition, the nature of most of the projects in the industry is multidisciplinary, and they usually require teams of engineers from different disciplines to perform a project. This paper presented the redesign process of Capstone projects to satisfy these requirements and provide students with the best possible experience in capstone projects.

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