Engineering and Engineering Technology Capstone Design Teams Lead to Successful Projects

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Abstract- The electrical engineering (EE) and electrical engineering technology (EET) programs at Penn State Harrisburg have two-course sequences that constitute the capstone design experience. In the first course, student teams learn about the formal engineering design process and project management then develop a detailed proposal for a project to be implemented in the following semester. Over the years, students from both electrical engineering and electrical engineering technology have worked in teams to complete their capstone projects. While electrical engineering students may have a strong theoretical background, electrical engineering technology students have strong hands-on experience, an important skill for building and troubleshooting electronic systems. This paper provides details about our approach in coordinating the activities in the two-course capstone design sequences and assessment results from industry sponsors, technical advisors, student self-assessment, and feedback through an "after-action-review" form. The results show high satisfaction with our capstone course structure, content, and approaches.

Introduction

The capstone design course is an essential milestone of engineering education and has been used to help fulfill ABET Criteria for Accreditation. While engineering curricula must include a culminating major engineering design experience [1], engineering technology programs must incorporate an experience that develops student competencies in applying both technical and non-technical skills [2]. In addition, educational programs have used the capstone course for various purposes, including equipping students with project management skills [3, 4, 5], addressing real-world problems [6, 7, 8], and as an assessment tool to meet professional accreditation requirements [9, 10, 11]. Although the process for implementing capstone projects varies between programs and disciplines, such projects normally take two semesters to complete and in the majority of cases, students are organized in teams of two or more [12, 13, 14].

Both the electrical engineering and electrical engineering technology programs at Penn State Harrisburg have two-course sequences that constitute the capstone design experience. In the first course, student teams learn about the formal engineering design process and project management. The training process includes topic selection, background research, engineering and customer requirements generation, functional decomposition, etc. This is followed by having students prepare a detailed proposal for a project to be implemented in the following semester.

The capstone sequence is structured to cover several important non-technical issues, like incorporating engineering standards and including realistic constraints such as economic, environmental, manufacturability, and safety. While engineering constraints are covered in earlier courses, capstone projects are expected to resolve the problems encountered by an engineer working in commercial, industrial, or government entities where the integration of constraints is part of the solution. The final report is a major outcome of the course and is expected to fully describe the project initiation, development, analysis, design, and verification phases. Other expectations include: Each team maintains a laboratory notebook that documents

the day-to-day activities of the project, attends review meetings with the instructor and their technical advisor throughout the semester, and submits a draft copy of the final report which is reviewed and returned to students, with comments and suggestions for improvements. Students will build strong teamwork skills and a cooperation mindset through continuous meetings with sponsors, advisors, and themselves.

Over the years, students from both electrical engineering and electrical engineering technology have worked in teams to complete their capstone projects. While electrical engineering students may have a strong theoretical background, electrical engineering technology students have strong hands-on experience, an important skill for building and troubleshooting electronic systems. Thus, the collaboration of electrical engineering and electrical engineering technology students usually leads to delivering projects efficiently and effectively. Another aspect that is worth mentioning here is that some of the projects are industry-sponsored and require multi-disciplinary teams that involve students from other disciplines, such as mechanical engineering and/or computer science. Students will benefit from interdisciplinary collaboration by effectively communicating with people from other specific domains.

This paper provides details about our approach in coordinating the activities in the two-course capstone design sequences and shares information about the supervision and evaluation of student teams, evaluation results based on feedback from faculty advisors, and student self-assessment and feedback through an "after-action-review" form that students complete at the end of the semester. The paper also provides details about a project that won first place in an IEEE regional competition.

Capstone Design Course Structure

Capstone Proposal Preparation Course:
The capstone design course consists of two consecutive courses, which are across two academic semesters. The first course (EE 405/ EET 419), capstone prep course, which serves as the capstone prep course, plays an essential role throughout the students' capstone design experience. This course requires that students do extensive research on their specific topics from a project management perspective. The research includes topic identification, in which students need to find their motivation to do the project with novelties; engineering requirements, in which students need to do a customer survey and summarize the customer needs with the project specifications, constraints, and standards; literature review, in which students need to read multiple research papers to know the background of the problem and review the most recent research solutions for the topics; the lifecycle of the product, in which students need to analyze and review their solutions in real product development cycle; functional decomposition, in which students are required to develop multiple levels of their project in block diagrams; Gantt chart and work breakdown structure, in which students need to identify the project schedule, and distribute the workload to each other in a balanced manner; and final project budget, in which students will collect all previous information and list all needed components to have an estimate of the total cost.

Compared to the implementation stage of the capstone design course, the prep course equips students with the required background information and the sense of the most innovative technologies. Students evaluate different approaches and balance the tradeoffs to find their own solutions with novelties. The prep course does prepare students for the implementation stage, which takes place in the second sequence of the capstone course (EE 406/ EET 420).

Capstone Project Design Course:

This course (EE 406) and its equivalent in the engineering technology program (EET 420) constitute the second course in the capstone project course sequences and involve 3 credits. The students start the design part of the sequence with a proposal they developed in the previous semester.

The structure of the course is based on three hours of class time twice a week. This designated time is used for both lectures and the laboratory. In the lecture, the instructor explains how to extend the proposal into a formal project report by the end of the semester. For the final report, a number of new sections need to be added, including:

- Subsystem development/design
- System Integration, testing, and results
- Environmental and safety concerns
- Legal, ethical, or political concerns
- Sustainability, and
- Expanded appendices.

The instructor explains how each section can be developed and what resources the students can use. However, the major portion of the designated time is intended to be used as lab time so that students can work on their projects. Other than the lectures, the instructor meets with each group separately at least three times during the semester. The purpose of these meetings is for the team to update the instructor on the progress of the project. Therefore, if any help is needed or students are facing challenges, the instructor can assist them as soon as possible.

The course assignments are designed to help students develop their project on time for the final capstone conference at the end of the semester. The projects are different every semester and may come from a variety of sources:

- Industry sponsored projects: each year an invitation for project sponsorship is sent out to local companies. These companies usually propose a few project ideas and provide financial support for students to work on these projects. In the past few years, we have had successful collaborations with companies such as TE Connectivity, Samtec, Amphenol, TRC Electronics, Phoenix Contact, and Penn State Hershy College of Medicine.
- Faculty sponsored projects: The instructor of the course invites members of the electrical engineering faculty and faculty from other engineering disciplines to share proposals or ideas suitable for capstone projects. These projects can be research and development based or focused on engineering design and prototyping.

- Student proposed projects: students have the freedom to propose their own ideas for their capstone project. In this case, a faculty member may help them improve their idea to be appropriate for a capstone project.

As soon as the project ideas have been identified and the teams are formed, each team selects a faculty member as its technical advisor. In the case of industry sponsored projects, usually, there will also be one technical advisor from the company too.

Each team will present their project to classmates two times during the semester through the midterm and final presentation. In the midterm presentation, students present their progress to date, share challenges they faced and how they tackled them, and describe their plan for the rest of the semester. However, final presentations, usually a week before the capstone conference, allow teams to practice their presentation skills for the big conference day and receive feedback from their peers and the instructor.

Roles of the Course Instructor and Technical Advisor

Timely and effective communication is key to the success of each capstone design project. At Penn State Harrisburg, the student group, technical advisor, and course instructor collaborate and communicate closely to make sure the project timelines are met. Almost all department faculty are involved in the capstone design projects by providing their own expertise as needed. The small class teaching philosophy guarantees we have a high faculty-to-student ratio so that project updates can be shared effectively. If a student group has a problem, the technical advisor and the instructor can provide quick and appropriate suggestions for the project direction, management, and resources.

The capstone design course is managed by a course instructor whose focus is to help students make appropriate progress toward meeting the course requirements and objectives. This starts by communicating the course requirements and establishing due dates and deadlines. In addition, the course instructor holds periodic review meetings to monitor progress and suggest corrective actions if the project is behind schedule. At the end of the semester, the course instructor schedules practice presentations to help students prepare for the annual student conference where students deliver oral presentations and participate in an exhibit to demonstrate the functionality of their projects.

Another important aspect of the course is the role of the technical advisor. Each project team must have a technical adviser that mentors students throughout the life of the project and guides them through any technical difficulties they may experience. Students must select a technical adviser that has expertise related to their project during the first course in the sequence. Each group must have at least one faculty member as a technical adviser. In the case of industry-sponsored projects, an industry representative serves as a co-adviser. To ensure proper advising, students are expected to have regular meetings with the technical adviser while determining major project goals and identifying technical specifications. The technical adviser in some cases also helps develop customer surveys that provide students with feedback regarding focus areas that they need to pay attention to when identifying a list of engineering requirements. As teams

start working on their project proposal, the technical adviser guides the major technical aspects of the project and the preparation of the required document.

Electrical Engineering and Electrical Engineering Technology Teams

At Penn State Harrisburg, some students are enrolled in the Electrical Engineering Technology program. These students receive more hands-on training compared to traditional Electrical Engineering students. Additionally, some engineering technology students are returned students who have associate degrees but want to pursue bachelor's degrees. These students usually have strong hands-on experience, and their past working background enables them to have good time management skills. Both types of students are enrolled in the same capstone design course. This combination gives students more benefits compared to the traditional capstone design course. The collaborative teamwork will take advantage of both EE students' strong theoretical modeling skills and EET students' strong hands-on skills. For example, some of our capstone design projects are directly brought in by our technology students with their current employers. Technology students usually request the capstone design course requirements before they register for the course. With these requirements, they discuss with their supervisors, choose the appropriate topic, and propose their project topic for approval. EE students are excited to join technology students' projects because they can learn current cutting-edge technology in the industry and gain more hands-on experience. At the same time, they can contribute their expertise in research skills, theoretical validation, and formal documentation.

There are also challenges when managing EE and EET students in the same group. For example, it is the instructor's responsibility to review the project plan and provide suggestions as appropriate. When a team consists of both EE and EET students, their methods to approach the final solution may not be the same. Their past training experience and background may generate different opinions on one problem and none of them want to compromise. In such a situation, the technical advisor and the instructor will need to initiate a group meeting to discuss the pros and cons of different approaches to reach a solution. Students found this very helpful for them to understand the problem from different perspectives and communication really resulted in better collaboration.

Multidisciplinary Projects Among Electrical Engineering, Mechanical Engineering and Computer Science

Having the capstone conference across the School of Science, Engineering and Technology provides an opportunity of collaboration between students from different programs. Usually, most industry sponsored projects require skills from different disciplines. Based on each project's needs, students from mechanical engineering (ME), EE/EET, or computer science (CS) will form teams to collaborate on specific projects. Students benefit from this situation in many ways, collaborating with students in other programs will expand their knowledge into other areas of science and engineering rather than only focusing on their own area of expertise, and will prepare them for the work environment in companies in the future where they must communicate and collaborate with people with diverse backgrounds on a daily basis. For example, one

practical engineering project involving ME and EE/EET students is proposed by a faculty from a nearby medical center. Faculty from both ME and EE/EET also closely collaborate to manage the team. Students need to choose either to follow the ME criteria or EE criteria to reduce the repeated documentation process. The corresponding course instructor will need to manage the project with their own criteria and provide students' performance to other departments.

Capstone Design Evaluation

The technical advisor is also involved in the assessment of the project. Technical adviser evaluation is worth 10% of the final grade of the capstone project. Table 1 shows the evaluation criteria for technical advisors of the projects. Each team will be evaluated based on how they performed as a team, the technology that they used on their project, the design they developed and how they present the results and outcome of their project.

Table 1: Technical Advisor Evaluation Rubric

Criterion	Exemplary (4)	Accomplished (3)	Developing (2)	Beginning (1)
Teamwork: Student was able to work as a team and played a key role in organizing and facilitating group learning				
Timely Meetings: The students scheduled timely meetings with the technical advisor				
Experimental Design The students could design reasonable experiments based on understanding of the project				
Technology The student was able to use a variety of appropriate sources to conduct experiments on the project				
Analysis and Presentation The student was able to appropriately report and display the results and use analysis techniques suitable for the type of data collected				

In the capstone course, students typically work on a project that demonstrates their skills and knowledge gained throughout their academic program. The final grade for this course includes a portion (20%) that is based on the presentation and demonstration of the project at the capstone conference. This means that students will be evaluated by a panel of faculty members who attend the conference and will assess their projects using a set of rubrics. The rubrics are designed to provide a structured evaluation process and ensure that all projects are evaluated fairly and consistently. The faculty members' scores will be averaged to determine the final evaluation score for each student. This process helps ensure that students have a clear understanding of what is expected of them and have an opportunity to showcase their hard work and achievements. Tables 2 and 3 show the rubrics for the presentation and demonstration respectively.

Table 2: Capstone Design Presentation Rubric

Item	Score	Comments
Audience motivation (sufficient description of the project and innovation to pique your interest in hearing more)		
Overall technical content (sufficient use of quantitative description for engineering requirements, design and results)		
Presentation (clear, engaging, eye contact, word choice, timing [about 12-18 minutes] – average for team)		
Presentation support (PowerPoint slide effectiveness)		

Table 3: Capstone Design Demonstration Rubric

Item	Score	Comments
Audience motivation (sufficient description of the project and innovation to pique your interest in hearing more)		
Overall technical content (sufficient use of quantitative description for engineering requirements, design and results)		
Functionality of the printed circuit board subsystem (proper testing and demonstration of designed printed circuit board in the project)		
Demonstration support *(Clear and effective support of the project functionality by demonstration of various tests)*		

Along with the presentation and demonstration of the capstone project, the final report is another major component of the final grade. The report serves as a comprehensive documentation of the project, including its objectives, methodologies, findings, and conclusions. Students are expected to follow specific Guidelines for the report, which typically includes sections such as an introduction, literature review, methodology, block diagram, results, discussion, and conclusion. The quality of the report will be evaluated using a rubric as the one outlined in Table 4. This rubric will assess factors such as the clarity and organization of the report, the quality of the research conducted, and the effectiveness of the analysis and conclusions presented. By providing clear guidelines and evaluation criteria, the final report ensures that students demonstrate their ability to communicate their research and findings effectively and contribute meaningfully to their field of study.

Table 4: Capstone Design Final Report Rubric

Name(s):				
	Included?	Quality	Weight	Score
Element	(Y or N)	(1 to 5)		
Title page	Y		0%	
Abstract	Y		3%	
Acknowledgements	Y		0%	
Table of Contents	Y		0%	
Tables of Symbols, Figures, Equations	Y		0%	
Introduction	Y		3%	
Technical History/Literature	Y		5%	
Lifecycle of Similar Products	Y		3%	
Customer Requirements	Y		3%	
Environmental/Safety	Y		3%	
Legal, Ethical, Political	Y		3%	
Sustainability	Y		3%	
Constraints	Y		3%	
Standards	Y		3%	
Engineering Requirements	Y		5%	
Level 1 Decomposition	Y		0%	
Level 2 Decomposition	Y		5%	
Level 2 Decomp Tables	Y		3%	
Subsystem Development/Design Tradeoffs	Y		10%	
System Integration/Test Results	Y		10%	
PCB Design	Y		10%	
Project WBS	N		3%	
Project Schedule & Budget	Y		3%	
Summary/Conclusions	Y		4%	
List of References	Y		0%	
Appendices	Y		0%	
Grammar, writing style	Y		10%	
Captions, Figures, Equations, etc.	Y		5%	
Total			100%	

IEEE Award Winner Project

The success of our approach in guiding the students to develop their idea and design a functional prototype has been proven in many ways such as returning our industrial sponsors with more projects each year and winning awards. In Spring 2022, Tyler Rupp, one of the top students, won the 2022 Institute of Electrical and Electronics Engineers (IEEE) Susquehanna Section Capstone Award for the design and development of "smart" shoes that can track the wearer's weight, steps, and distance (see Figure 1). He proposed the idea of smart shoes himself and worked with his technical advisor to develop and build a prototype.

Six colleges from the region competed in the IEEE competition that year. "The 2022 Second Annual IEEE Capstone Competition" had many well-planned and well-engineered project submissions. All of these project submissions have demonstrated the technical, the practical skills, and the innovation needed for these students to graduate and begin their careers as engineers," said Luis Carlos Torres Jr., IEEE Susquehanna Section past chair and awards committee chair. The students' project "was very special because this student not only planned and developed a functioning prototype, but did it like a true engineer, with a business proposal, marketing, and adhering to a strict budget plan," Torres said.

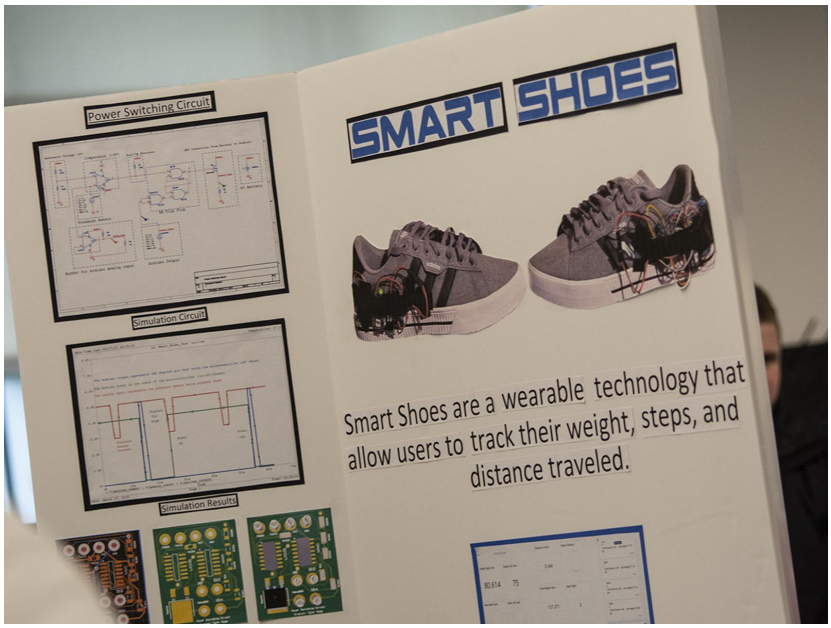

Figure 1:A Trifold Showing the Smart Shoes Project

Rupp now works as a successful electrical engineer at Philips, a company that makes transducers for ultrasound equipment. The student mentioned that the capstone experience was valuable, noting it was a longer project, similar to what he'd do in a work environment, where he had to learn new skills along the way.

Conclusion

The capstone project is an important milestone for engineering students. This is the last learning opportunity before the start of their career paths. If the capstone design project is done in the right format, it will prepare them for their future careers by teaching them not only technical skills but also important social skills, such as teamwork, time management, problem analysis, communications, etc., to prepare them for future careers. Allowing students from different disciplines to work on multidisciplinary projects has provided our students with invaluable skills and led to the planning and implementation of successful projects. The annual School Capstone Design Conference, held in the spring of each year, has given our students the opportunity to present their projects and showcase their skills and expertise. It has also strengthened our relationships with industry and the community. The capstone design course approach has been proven to be an effective way to prepare our students ready for their future development no matter whether the students go for industry jobs or advance to higher education.

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