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Experiential Learning in Engineering Education Through Senior Capstone Design

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ABSTRACT

At most, if not all, colleges and universities in the US offering engineering and technology programs, a two-semester capstone design sequence is an integral part of the final year of the curriculum. This represents an attempt to help students transition from study to practice of engineering while providing program administrators a tool to evaluate the overall effectiveness of the program in terms of the ability of the students to integrate and utilize knowledge gained from classroom study to solve real-world problems. It has also become a crucial component in the ABET accreditation process and helps improve curriculum vitality in order to remain relevant in the rapidly changing world of technology. This paper describes one of the many practices of directing this two-semester design sequence from the author's experience directing the course and/or serving as faculty advisor to students' teams for the past eleven years at the Citadel's department of Electrical & Computer Engineering. The narrative is not based on data-driven observations and conclusions, and thus, not intended to represent best practices to be adopted by every institution. Rather, it is the author's intention to share many successes and pitfalls involving issues ranging from team composition and project selection to effective utilization of project management methods and other design considerations, such as ethics, testing, and manufacturability. Furthermore, several strategies for public dissemination of the projects are discussed including oral and poster presentation, professional societies sponsored competition, and industry/company feedback. It is hoped that the paper provides a model that may serve as an exemplar for other similar programs.

Keywords: Engineering design, capstone sequence

Introduction

Experiential learning, according to Kolb 1984, p. 41, is defined as "the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience." Simply put, experiential learning is a process through which students develop knowledge, skills, and values from direct experiences outside a traditional classroom setting. Experiential learning encompasses a variety of activities including internships, service learning, undergraduate research, study abroad, and other creative and professional work experiences. Well-planned, supervised and assessed experiential learning programs can stimulate academic inquiry by promoting interdisciplinary learning, civic engagement, career development, cultural awareness, leadership, and other professional and intellectual skills.

In engineering education, experiential learning is usually incorporated into the curriculum in the form of capstone senior design. At most, if not all, colleges and universities in the US offering engineering and technology programs, a two-semester capstone design sequence is an integral part of the final year of the curriculum. This represents an attempt to help students transition from study to practice of engineering while providing program administrators a tool to evaluate the overall effectiveness of the program in terms of the ability of the students to integrate and utilize knowledge gained from classroom study to solve real-world problems. Consequently, the assessment outcomes help improve curriculum vitality in order for the program to remain relevant in the rapidly changing world of technology.

Generally, capstone courses are intended to be intensive experiences in critical analysis and synthesis, designed to broaden students' perspectives beyond their culture or discipline, and provide an opportunity for integration of previous courses in the major and in the core curriculum. The summative nature of capstone sequences usually results in course content spanning a wide range of outcomes and skills, which are brought together through the solution of complex problems by student teams. This is consistent with engineering accreditation requirements set forth by the Accreditation Board for Engineering and Technology (ABET, 2015), which requires accredited engineering programs demonstrate that their graduates have:

a) an ability to apply knowledge of mathematics, science, and engineering;
b) an ability to design and conduct experiments, as well as to analyze and
c) interpret data;
d) an ability to design a system, component, or process to meet desired needs
e) within realistic constraints;
f) an ability to function on multi-disciplinary teams;
g) an ability to identify, formulates, and solves engineering problems;
h) an understanding of professional and ethical responsibility;
i) an ability to communicate effectively;
j) the broad education necessary to understand the impact of engineering solutions in a global and societal context;

i. a recognition of the need for, and an ability to engage in life-long learning;
ii. a knowledge of contemporary issues; and
iii. an ability to use the techniques, skills, and modern engineering tools
iv. necessary for engineering practice.

Senior capstone design is usually offered as a yearlong sequence of two courses starting in the Fall semester and culminating in the Spring semester for schools that adopt a semester system. Instead of a usual one-semester course, the additional time not only allows students to more fully develop their design and conceptualization abilities, but also allows for stronger development of teamwork and other project-related skills. Moreover, the two-course sequence provides integrated coverage of multiple aspects of design, including project management, engineering economics, safety and reliability, engineering ethics, communication, and the design and analysis process. Finally, the additional time allows for increased development of technical communication abilities, with more deliverables in the form of both written and oral presentations scattered throughout the two-semester sequence.

The purpose of this paper is to describe one of the many practices of directing this two-semester design sequence from the author's experience directing the course and/or serving as faculty advisor to students' teams for the past eleven years at the Citadel's department of Electrical & Computer Engineering. The narrative is not based on data-driven observations and conclusions, and thus, not intended to represent best practices to be adopted by every institution. Rather, it is the author's intention to share many successes and pitfalls involving issues ranging from team composition and project selection to effective utilization of project management methods and other design considerations, such as ethics, testing, and manufacturability. Furthermore, several strategies for public dissemination of the projects are discussed including oral and poster presentation, professional societies sponsored competition, and industry/company feedback. It is hoped that the paper provides a model that may serve as an exemplar for other similar programs.

Description of the Two-Semester Capstone Sequence

This section describes how the two-semester design sequence is administered at the Department of Electrical & Computer Engineering, The Citadel's School of Engineering. The two courses are ELEC 421 Design I, and ELEC 422 Design II. Course description reads as follows:

> Initiation, design, scheduling, documentation and reporting on a major design project. Normally accomplished by students working in small groups. All students will make written and oral presentations on their contributions to the project. Financial, legal, ethical, societal, regulatory, environmental, manufacturability, and quality issues will be discussed and will constrain the designs as appropriate.

ELEC 421 Design I

The first course in the sequence is ELEC 421 Design I. It is a three-credit course with one-hour lecture component and four-hour laboratory component (five hours per week workload). The following is a typical lesson plan as shown in figure 1 below.

Week no.	Content
1	An overview of the engineering design process Team selection/assignment
2	Project selection & initial scoping
3	Resume, academic portfolio Guest lecture by the director of the Career Center
4	Preliminary project proposal submission
5	Primer on practical amplifier design, solid-state switching and microcontroller applications
6	Introduction to project management
7	Oral presentation preparation
8	Specification writing and control
9	Formal project proposal preparation
10	Leadership seminar
11	Ethical and legal considerations in design
12	Fall/Thanksgiving break
13	Formal project proposal presentations
14	Proof-of-concept demonstrations

Figure 1: A typical lesson plan for ELEC 421 Design I.

In addition to the usual coverage of the materials on the engineering design process, communication skills, and project management methods, several noteworthy considerations including team and project selection processes are posited and expanded below. These highlights are based on eleven-year experience serving as the course instructor and/or faculty technical advisor.

First, student teams are quickly formed, usually during the first week of class. A team of four or five members has proven to work well. Attempt is usually made to assign students to teams according to their chosen preferences; however, the course instructor often exercises his/her judgement to take into account the overall GPA of the teams resulting in relatively evenly spreading of GPA for all teams. This can prove useful in avoiding teams with all high- or all low- GPA members. Although GPA is not a reliable indication of teams' performance and success, some level of GPA spreading had proven to significantly contribute to a successful design.

One class period is devoted to team members familiarizing themselves with one another through ice-breaking activities. This will later allow the teams to effectively manage the project as personal traits and subject-matter strengths are discovered and discussed. In addition, the significance of teamwork and methods of conflict resolution are particularly emphasized. A consensus-building exercise is introduced by asking teams to choose a team name and a team leader. Having a team name promotes a strong sense of enthusiasm and dedication to a common goal that unites a group. Teams are also discouraged from procrastinating to avoid overloading the end of the semester and reminded that they will be assessed based on deliverables, not tests or exams, as is the case in professional engineering practice they will encounter after graduation. As experience indicates, this proves to be very useful toward team's success since students are used to work in groups no larger than two as in class projects and/or laboratories.

Next, each team member is tasked with the responsibility of project selection under the guidance of the course instructor. Sources of project ideas include team members, faculty's pet projects, professional societies sponsored competitions, and industrial/company sponsored projects. Teams are encouraged to do as much research on their chosen project as possible to maximize the chance of being approved by the course instructor and the rest of the faculty members. They are also encouraged to discuss project idea with faculty members and possibly choose their project technical advisor. Furthermore, when preparing their preliminary project proposal, teams are required to answer the following three questions to help assess their concept. They are:

1) what are you trying to do?
2) how will you approach the problem and why will you succeed?
3) how will you know at midterm if you are succeeding?

Once the preliminary project proposals are submitted, all faculty members meet to discuss viability of the proposed projects to ensure that the project can be carried out successfully within the given timeframe. During the meeting, faculty members are encouraged to advocate for certain projects that suit their interest or expertise in order to facilitate the assignment of project technical advisor. At the end of the meeting, faculty members as a whole either approves/approves with revision or rejects the proposals. Results are then conveyed to the teams and appropriate actions are taken accordingly. This signals the start of the next phase of the design.

Finally, after the approval of their preliminary proposal, teams are now ready to start immersing themselves in the design process, which will culminate in a written submission and an oral presentation of their formal project proposal followed by a proof-of-concept demonstration at the end of the semester. A proof-of-concept demonstration is considered one of the major deliverables for the course. It represents necessary laboratory work to prove that the project is technically feasible and can be carried out to fruition at the end of the second semester. Throughout the remaining of the first semester, team's performance is continually assessed through bi-weekly status reports, regular meetings with their technical advisor, and various presentations. To avoid a last-minute rush, teams are required to submit a draft of the formal proposal along with technical specifications for feedback by the course instructor and project advisor. The purpose of the written project proposal is to stress the importance of technical writing skill while the oral portion serves to simulate the product-pitching presentation with marketing spin in order to convince upper management or investors.

ELEC 422 Design II

The journey continues in the second follow-on course, ELEC 422 Design II. Similarly, it is a three-credit course with one-hour lecture component and four-hour laboratory component (five hours per week workload). The following is a typical lesson plan as shown in figure 2 below.

Week no.	Content
1	Poster preparations & presentations
2	Laboratory work
3	Design review
4	Laboratory work
5	System Reliability
6	Laboratory work
7	Testing Principles & Guidance
8	Laboratory work
9	Elements of Technical Reports/Papers CEEDS Paper Overview
10	Laboratory work
11	Spring Break
12	The Citadel Electrical Engineering Design Symposium (CEEDS) Presentations
13	Guest lecture on product development
14	Project/Prototype Demonstration

Figure 2: A typical lesson plan for ELEC 422 Design II.

Although more time are intentionally allocated for laboratory work, a number of lectures on product development cycle such as testing, reliability, manufacturability, etc. are scheduled. In preparation for the design symposium, teams are also taught how to prepare a technical paper summarizing the design. The paper is formatted according to the professional society standard. These lectures are deemed necessary to keep students focused on the career as an electrical engineer.

For the second semester, a number of significant deliverables are required. For one thing, teams must prepare a poster presentation to showcase their design during engineer's week celebration in February. This deliverable is designed not only to guard against procrastination and a lack of productivity, but also to introduce teams to an increasingly popular form of technical presentation. Since the engineer's week celebration is well attended by the general public, the presentation is also aimed at a way of publicizing the designs. Secondly, another deliverable that forces public dissemination of the projects is the so-called CEEDS presentation. CEEDS stands for The Citadel Electrical Engineering Design Symposium where teams orally present their project along with published proceedings of technical papers summarizing detailed realization of the design. Finally, at the end of the semester, two deliverables are required, namely a final project demonstration and a comprehensive final report. A final project demonstration serves as an assessment tool to gauge the level of success of the project against a testing plan that is negotiated well in advance. All team members along with the course instructor and the project advisor participate in the demonstration. In addition to the face-to-face demonstration, some teams also choose to document and publicize their accomplishment in the form of a video demonstration to be later uploaded to YouTube®. Moreover, a well-written comprehensive report detailing the design, which allows understanding and faithful reproduction of the project, serves as a final deliverable.

Conclusion

For roughly the past forty years, engineering senior capstone design has been successfully used to help students bridging the gap between academic and professional experience. It represents a form of experiential learning for students and serves as an assessment tool for program administrators to evaluate the effectiveness of the program in order to allow the program to evolve with rapid changes in technology and remain relevant.

The paper offers a detailed description of how a two-semester engineering capstone design sequence is managed effectively in a relatively small- to medium-sized Electrical & Computer engineering department with enrolment of about 50 students. It is the author's intent to share these experiences with others in similar programs while keeping in mind that this is not to suggest a one-size-fits-all kind of scenario. Subtle observations and considerations involving the issues of team formation, project selection, and effective deliverables are noteworthy and have been proven to enhance the success of capstone design for both students and instructors.

References

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