Challenges and Lessons Learned by a Practicing Engineer Teaching Capstone Design for the First Time

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In this paper, the author reflects on his experience and lessons learned teaching capstone course since August 2019. Further, he discusses the reasons why we do capstone projects, objectives of the mechanical engineering capstone program at George Mason University (Mason), funding streams for capstone projects and the enrichment of the educational experiences of senior students. Purpose of the paper is to pique the readers' interest in generating ideas for capstone programs, have a healthy discussion of the status quo, how to improve the capstone planning and funding process, and enhance student learning experiences through capstone. Currently in his third year of teaching capstone courses, the author will generate discussions based on experience in engineering practice, ABET requirements, Mason curricular requirements, feedback from students and collaboration with sponsors. Author will use his extensive experience that includes 30 years of engineering practice, 20 years as an ABET volunteer expert in which he served as a commissioner with the Engineering Accreditation Commission of ABET for the last five years, to guide the discussion and generate ideas for way ahead.

Keywords: *accreditation*, industry sponsored, prototyping, engineering practice

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Introduction

Capstone design is generally taught for a number of reasons such as curricular requirement, ABET requirement and the need to provide a real-world engineering experience before students earn their bachelor degree. Most engineering programs use one- or two-semester long design course as the culminating design experience for senior students. This paper presents author's experience in developing industry-sponsored projects, students' communication with sponsors, and prototyping and final product at the end of the academic year. Author's experience in multiple aspects will add to this interesting discussion. First, Mason's Mechanical Engineering (ME) program is very young and author's first year was the program's fourth year of capstone program. Second, during his first year, the pandemic arrived without any notice and adjustments to the program were needed. Author had transitioned from an "engineer" to teacher in August 2019 and his primary role is to manage the capstone program and teach the senior design course for the mechanical engineering program at George Mason University (Mason). The sudden and unexpected arrival of pandemic in March 2020 was a lesson in planning, leadership and risk management for the author as well for his students. Objectives of this paper are to:

1. Recapture reasons for a capstone course
2. Explain implications on accreditation by ABET
3. Discuss the benefits of industry sponsored projects
4. Explore funding models for ME capstone program at Mason
5. Discuss advising and student experiences based on their feedback
6. Recall conducting capstone days under different modalities during pandemic
7. Engage the audience to discuss better way forward on teaching capstone program so students will get the best real-world experience possible.

Capstone Design and ABET Accreditation

Engineering programs have used capstone programs to partially fulfill curricular requirements. ABET Criteria for accrediting engineering programs during the 1999-2000 accreditation cycle[1] stated "Each educational program must include a meaningful, major engineering design experience that builds upon the fundamental concepts of mathematics, basic sciences, the humanities and social sciences, engineering topics, and communication skills. The scope of the design experience within a program should match the requirements of practice within that discipline." Beginning with the ABET Engineering Accreditation Commission's (EAC) Criteria EC2000, effective for the 2001-2002 accreditation cycle, the requirements were changed to explicitly state "Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier coursework and incorporating engineering standards and realistic constraints that include most of the following considerations: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political." Latest ABET EAC Criteria for the 2021-2022 accreditation cycle require "a culminating major engineering design experience that 1) incorporates appropriate engineering standards and multiple constraints, and 2) is based on the knowledge and skills acquired in earlier course work." The student outcome 2 of the criteria states "an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors."

Although the requirements have evolved gradually, essentially it requires a major design experience with number of considerations and must incorporate engineering standards and multiple constraints. Lack of incorporating engineering standards and constraints in senior design invariably results in a shortcoming during ABET's program evaluation visit. Although ABET criteria do not require fabrication, testing or any type of construction, mechanical engineering programs at numerous institutions require prototyping and/or machine shop, "hands-on" experience which is the case at Mason. It is a great experience when students can go through the full range of a project, starting with negotiating a project proposal with the sponsor, then do planning, design, prototyping, testing and submitting the completed product to the sponsor. Together with project management and risk management, students gain a real-world experience, and it is certainly more than what ABET criteria requires. Capstone design in our mechanical engineering is required to meet the criteria for university's writing intensive course. Mason's Writing Across the Curriculum Committee sets the standards for the writing intensive criteria. It makes the students think the purpose of writing as to learn, think, and communicate, and not merely following the grammar rules learned in composition courses previously.

Funding and Team Size of Capstone Projects

When a program requires students to do prototyping to include "building" an artifact, there is a cost associated with it. Depending on the extent of the design, the program's budget may not cover this added cost unless it is sponsored by external entities. Since the inception of our capstone programs six years ago, 100% of the projects have been sponsored by industry or government, external to our department. Table 1 summarizes the growth in students in the senior design course at Mason for the last six academic years. As the enrollment has grown, it has been a challenge to obtain adequate number of sponsored projects. This situation became more acute for the class of 2020-21 when most of the companies operated in a virtual mode and it was not possible to visit in-person to solicit support. Although the author prefers a team size of four students for optimum productivity and student experience, the teams were formed with five or six students as a result of inadequate number of projects. As reported by Watkins[2], it is difficult to and takes a lot of effort to document awarding a failing grade since most of the work submitted by students are done in a team effort. Therefore, the question is what other models can be used to generate projects for capstone students and to keep the team size reasonable? Author is considering faculty created projects, students suggested project ideas and having multiple teams work on the same project as an internal competition. What would be the pros and cons of each of these models? Student surveys conducted at the end of the year for senior design course indicated that when teams have five or six students, one or two students get by simply doing the bare minimum amount of work. Also, working on sponsored projects and with industry personnel, it becomes a networking opportunity and occasionally students find employment because of their involvement in sponsored capstone projects.

Table 1 – Number of students, projects and team size

Academic Year	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
Number of Students	19	49	68	59	92	80
Number of Teams	4	10	14	14	17	20
Students per Team	5	5	5	4	5	4

During the AY 2018-19 and 2019-20, student teams consisted of four or five students per team. As explained previously, teams had either five or six students per team during AY 2020-21. All the teams had four students each during AY 2021-22 and few teams had students from other engineering fields and computer science due to multidisciplinary nature of projects. Student feedback indicated that the workload was more for a four-person team and five members per team would be better. Although unusual, when one student quit the program after one semester, his team was left three students and it was very difficult for the team to complete the project in the spring semester. In author's opinion, a capstone team should consist of four or five students, number depending on the expected complexity of the project. For projects with average complexity, there was no increase in quality of delivery or performance with more than five on a team.

Comparing Origins of Capstone Project Ideas

Majority of our capstone projects are industry sponsored and thus to a larger extent, involve problems initially defined by the sponsors and fine-tuned by the student teams in consultation with sponsors. There were few projects which were originated with ideas from faculty members. As stated by Howe, et. al.[3], students experienced increased networking opportunities when they worked on industry sponsored projects although they usually started with very vague project scope. This approach gives students more exposure to what they will experience in engineering practice. Project ideas initiated by faculty members seemed to be "well-defined" and had the students focused on tasks from the beginning. Curricular requirements are met as long as a project provides culminating design experience. However, it is the author's opinion that providing opportunities to improve soft skills and increase networking opportunities are very desirable outcomes of capstone experience.

Advising and Student Experience

Based on student survey conducted at the end of each academic year, students are very satisfied with their capstone experience and opportunity to interact with real-world engineering companies. We have about 13 full-time faculty members and a number of adjunct faculty members in our department. Two faculty members generally teach four sections of senior design, limiting enrollment to 25 students per section. Each team is assigned a faculty member, or technical advisor to mentor and guide the students during the two semesters. Advisors are assigned to a project that aligns with their areas of expertise. All full-time faculty members are required to mentor one team as part of the service requirement to the program. When necessary, adjunct faculty members are asked to advise a capstone team and it is voluntary on their part. As most adjunct faculty members are practicing or retired engineers, they bring a wealth of knowledge to share with the students and it has served the students well. In addition to the faculty advisors, the course instructors serve as the secondary advisors. Students indicated that success of the team strongly correlated to the level of engagement by sponsors. Students indicated "hands-on" activities have helped them and kept the capstone process more interesting compared to a theoretical design experience. Those teams who met the sponsors periodically had a higher rate of successfully completing the projects on time than those who did not.

Capstone Days

Towards the end of the academic year, our program has had a capstone expo day, simply known as the capstone day in which students showcase their creativity and prototypes. It is a day of celebration for graduating seniors besides the university commencement day. Capstone day is held on a smaller scale than the university commencement event, and students often invite family and friends to the event. The pandemic arrived in March 2020 during the author's first year and the in-person capstone day had to be cancelled. With expedited planning, our program managed to host a "Virtual Capstone Day" in May 2020 in which all student teams presented their projects. During spring 2021, public health situation improved slightly but the pandemic did not end. Our program hosted a capstone day event over two days in May 2021 in a hybrid format where the students had static displays with limited attendance and visitors were allowed in a capacity controlled, socially distanced manner. We held an in-person capstone day on May 5, 2022 and it was well attended by alumni, faculty, sponsors, students, families, friends and supporters of the mechanical engineering program.

Conclusion

Through reflection, the author has discussed some of the challenges that arose during his first years of teaching mechanical engineering capstone course. Further, he has discussed it in light of his decades of experience in engineering practice and years of service to ABET as a volunteer expert. Author would like to know best funding mechanisms to sponsor a large senior design class in which 100% of the projects are industry sponsored. All of us who teach capstone design course can share lessons learned and enrich and improve future students' culminating design experience. This is the motivation for the paper and the author plans to engage the audience in this endeavor.

References

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