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Achieving Capstone Design Objectives During Necessitated COVID-19 Online Teaching

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Achieving Capstone Design Objectives and Outcomes

During Necessitated COVID-19 Online Teaching Formats

Abstract

A capstone course is usually the peak experience for students in most engineering education programs. In addition to any specific learning objectives, capstone courses provide students with the finishing touches needed for fielded practice, the opportunity to boost their confidence, and the platform to demonstrate the attainment of the program student outcomes. Depending on the program and discipline, engineering capstone courses usually take the form of open-ended design projects that integrate and synthesize what students have learned through the academic program in a team setting experience.

As defined by ABET, "Engineering design is a process of devising a system, component, or process to meet desired needs and specifications within constraints. It is an iterative, creative, decision-making process in which the basic sciences, mathematics, and engineering sciences are applied to convert resources into solutions. Engineering design involves identifying opportunities, developing requirements, performing analysis and synthesis, generating multiple solutions, evaluating solutions against requirements, considering risks, and making trade-offs, for the purpose of obtaining a high-quality solution under the given circumstances." Considering the importance of capstone courses to program accreditation, learning objectives and outcomes that are aligned with the ABET engineering design definition should be established and achieved.

This paper discusses and addresses the achievement of the learning objectives and student outcomes of a capstone courses, aligned with the ABET engineering design definition, during the online teaching format necessitated by COVID-19. Based on the experience with the online format, project-based engineering capstone courses could be successfully taught in the online format. However, there few issues that must be addressed for achievements of the course learning objectives and attainment of student outcomes. While some of these issues are directly related to the restrictions imposed by the COVID-19 pandemic and not necessarily to the online format, addressing these issues is necessary for successful online capstone experience. To demonstrate the achievements of the course learning objectives and attainment of student outcomes by addressing the online format issues, some examples of students' engineering capstone project work are presented.

Introduction

Capstone courses provide students with the educational culminative and integrative experiences, the finishing touches needed for fielded practices, the platform to apply the program acquired knowledge and skills, and the opportunity to build their own confidence. To achieve these intents

and educational objectives, capstone courses are usually offered at the senior level by most engineering programs. For their role, intent, and position in the program capstone courses usually share most, if not all, program educational objectives and student outcomes. As a result, capstone courses are key in assessing student outcomes and tracking the achievement of the long-term program educational objectives. Consequently, these courses are central to the program quality, continuous improvement, and accreditation [1-5].

There are several approaches for developing and delivering a capstone course [1], most engineering capstone courses, however, take the form of open-ended design projects that integrate and put to practice what students have learned through the academic program in a team setting experience [6]. For these project-based capstone courses, face-to-face classes have been the norm due to the physical requirements in the design, build, and validation of a capstone project along with the necessary, teamwork, interactions, planning, management, and communications. While there have been no specific literatures about fully developing and delivering capstone courses via online format, there have been some effort about virtual design studios and design courses [7, 8]. There have been also some efforts towards remote rapid prototyping and virtual delivery of oral presentations [9, 10].

With the safety concerns caused by COVID-19 and the state mandated restrictions necessitated by the pandemic, all University courses including the engineering courses were forced to move online with very few exceptions such as engineering and manufacturing labs. All courses moved online during the winter 2020 semester. As the case for any public University, the majority of enrolled students are state residents with some out-of-state and international Students. Due to the shift to the online format, on-campus students moved to their own homes including the out-of-state students. Due travel and visa restrictions, international students stayed at their own residence off-campus.

As a result of classes moving online, the transformation of the most physically dependent assembly and validation phase of the project-based senior level engineering capstone design course started during the winter 2020 semester. The full transformation and delivery of the capstone course to the online format continued during the full academic year of Fall 2020 and Winter 2021 semesters. While the authors have developed and delivered many undergraduate and graduate courses in online format, this capstone course was always taught in face-to-face format for over thirty years. To realize the capstone course essential role in providing students with the culminative integrative experiences, the finishing touches for fielded practices, continuous improvement of the program quality, and accreditation, the online transformation was focused on attainment of the same face-to-face course learning objectives and student outcomes. In the following, the main issues related to transforming a project-based engineering capstone design course to online format are discussed and addressed.

Capstone Course Learning Objectives and Outcomes

A project-based capstone course provides students with the platform to apply the program acquired knowledge and skills through a culminative, integrative, and open-ended design experiences [1]. To attain student outcomes, perform effective assessment, and ensure program accreditation it is imperative to adhere to the definitions developed by professional societies and accrediting organizations in developing course objective and outcomes. For engineering programs, ABET [11] defines design as: "Engineering design is a process of devising a system, component, or process to meet desired needs and specifications within constraints. It is an iterative, creative, decision-making process in which the basic sciences, mathematics, and engineering sciences are applied to convert resources into solutions. Engineering design involves identifying opportunities, developing requirements, performing analysis and synthesis, generating multiple solutions, evaluating solutions against requirements, considering risks, and making trade- offs, for the purpose of obtaining a high-quality solution under the given circumstances."

Taking the ABET engineering design definition into account, the course learning objectives and student outcomes of a previously developed capstone course [2] were modified. The modified course provides students with a comprehensive, logical, and realistic product development experience. The course intent is to foster creativity, develop students' teamwork, planning, management, and communication skills as specified by the following educational objectives and outcomes:

Objective 1: Cultivate creative thinking

1.1 Able to identify needs and opportunities
1.2 Able to brainstorm and create alternative design solutions.

Objective 2: Follow systematic identification of product attributes and criteria process.

2.1 Able to use systematic process to identify key product characteristics and attributes
2.2 Able to transfer desired product attributes to design criteria and engineering specifications

Objective 3: Follow project planning, management, and decision-making processes

3.1 Able to use project planning to plan tasks, timing, and deliverables based on established specifications
3.2 Able to execute plan, coordinate activities, and procure deliverables based on established timing

Objective 4: Practice teamwork and communication skills

4.1 Able to form teams and work effectively with others to achieve design goals.
4.2 Able to present ideas, plans and design alternatives in written and oral formats.

Objective 5: Practice design, synthesis, analysis, and simulation processes

5.1 Able to apply basic sciences, mathematics, and engineering sciences to convert resources into alternative design solutions.

5.2 Able to use modern tools to simulate and synthesize the conceptualized product in the intended environment.
5.3 Able to assess risks, make trade-offs, and obtain a high-quality solution under the given circumstances.

These established learning objective and outcomes have been implemented successfully in a face-to-face two semester Mechanical Engineering Technology capstone course. The capstone course consists of first semester with emphasis on the design/simulation phase and second semester with emphasis on the physical build/validation phase.

Teaching Capstone Course Online During COVID-19 Pandemic

As necessitated by the circumstances associated with COVID-19, the two-semester Mechanical Engineering Technology capstone course moved to online format during the build and validation phase second semester (Winter 2020). The design phase for this capstone course was completed in face-to face format during the first semester (Fall 2019). Despite the move to online format all projects' physical builds were completed as illustrated by the following example.

Example 1: Portable Tensile Testing Apparatus

The design and simulation phase for Portable Tensile Testing Apparatus, using two electrically controlled hydraulic cylinders [12], was completed in face-to face format during the first semester (Fall 2019) as shown in Figure 1. The build and validation were completed during the second semester (Winter 2020) online format necessitated by COVID-19. The designed and simulated concept shown in Figure 1, was built as originally intended and proven functional after assembly as demonstrated in Figure 2. With limited scope validation testing, the physically built apparatus performed the material testing with little setup required. The development and validation of the control software has taken longer than expected due to coding issues, but the project was fully completed before the end of the semester.

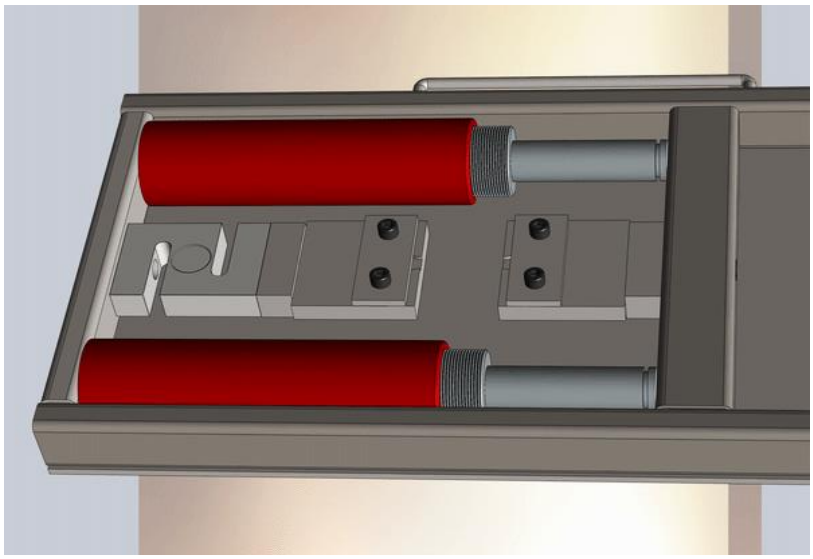

Figure 1- Virtually Designed and Simulated Portable Tensile Testing Apparatus [12]

Figure 2 - Physical Build of the Portable Tensile Testing Apparatus [12]

The first semester design phase of the Mechanical Engineering Technology capstone course started in online format, for new cohort of students, during Fall 2020. With fully online format, all projects' virtual design and simulations were completed during Fall 2020 and the Build/Validation started during Winter 2021, as illustrated by the following example.

Example 2: Personal Hovercraft

The design and simulation phase for affordable Personal Hovercraft [13], was completed in online format during the first semester of the capstone course (Fall 2020). The designed concept for the frame assembly is illustrated by Figure 3, and samples of the simulations are shown in Figure 4.

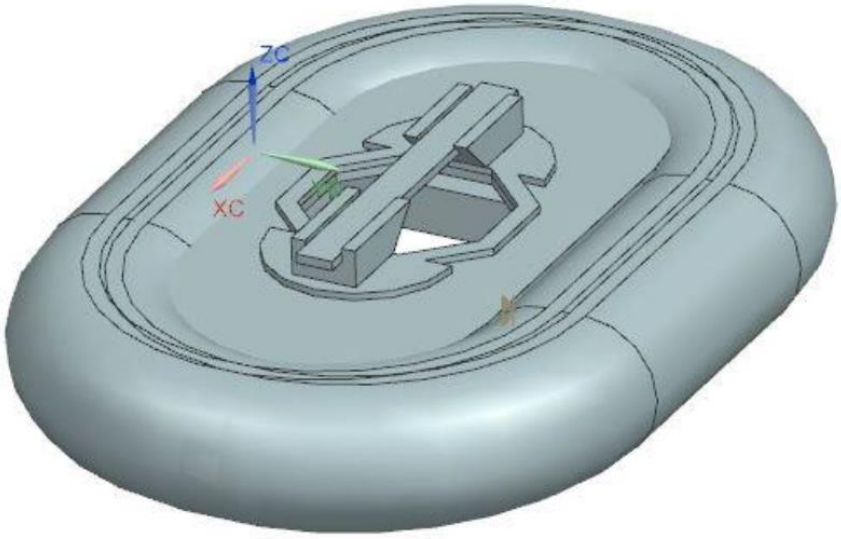

Figure 3 - Personal Hovercraft Virtual Frame Assembly [13]

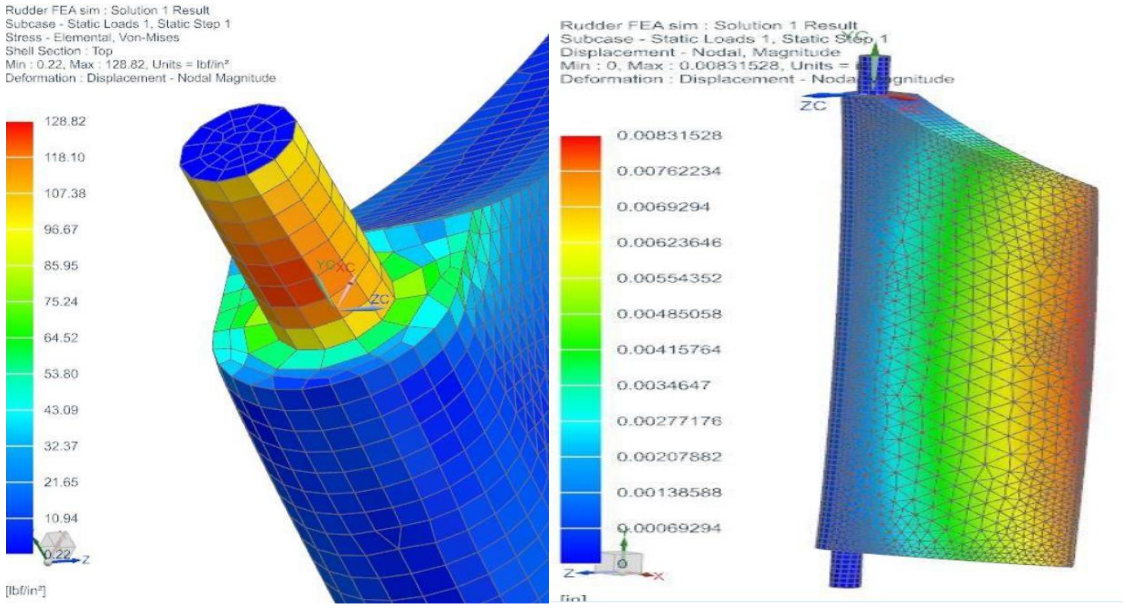

Figure 4 - Personal Hovercraft Virtual Rudder Stress and Displacement Simulations [13]

The build and validation phases for the Personal Hovercraft started with the course second semester online format during Winter 2021[14]. The designed and simulated frame concept shown in Figure 3, were built as demonstrated in Figure 5. The full physical assembly of the Personal Hovercraft is shown in Figure 6.

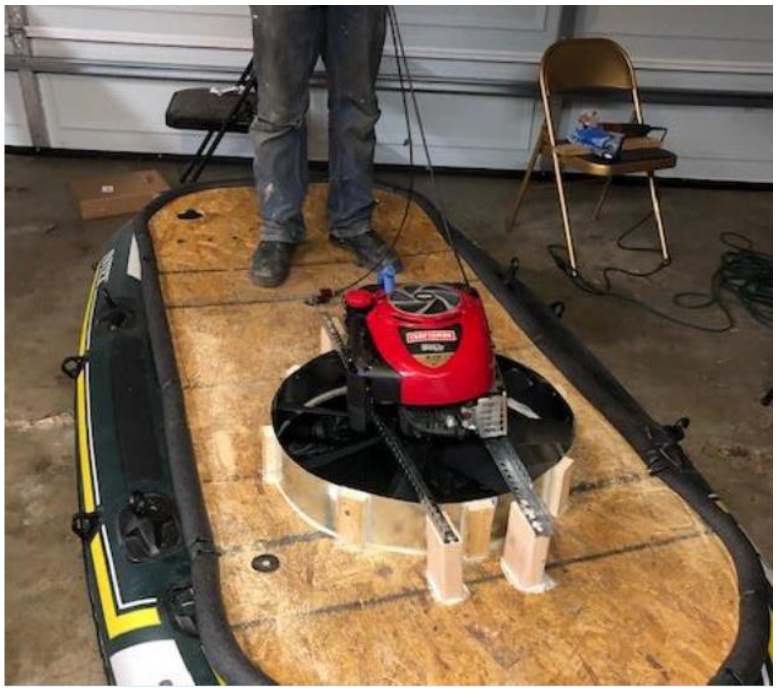

Figure 5 – Physical Assembly of Personal Hovercraft Frame [14]

Figure 6 – Full Physical Assembly of Personal Hovercraft [14]

Capstone Course Online Format Issues

The students' surveyed about the online format in Winter 2020 and near the end of the Winter 2021, made the following two comments that were mostly agreed upon by the class: "the online format provided more flexibility than the face-to face". On the other hand, for some students, "the lack of physical interaction limited the overall energy and enthusiasm that come from working closely with a team." Because the second comment is mostly related to the COVID-19 Pandemic restrictions and to social distancing, limitations on physical team interaction would not be necessary for a normal online format. Accordingly, for normal online format without restrictions on physical team meetings, the students feel that the online format would provide more flexibility.

As for the quality of the projects, the final products developed during the online format were at par with the face-to-face classes. For the Winter 2020 and Winter 2021 senior capstone classes, student completed and validated their products similar to any face-to-face class. The online format, however, provided students with additional learning experiences that are useful in building the virtual collaboration skills needed for global product development [15-17]. However, based on the online format experience necessitated by COVID-19, there are some issues that must be addressed to fully achieve the project-based capstone course learning objectives and student outcomes. These issues were observed during instruction and were validated through communication with the students. While some of these issues are directly related to the restrictions imposed by the COVID-19 pandemic and not necessarily to the online format, addressing these issues is necessary for

successful online capstone experience. These issues are summarized in Table 1, as it pertains to each course learning objective and student outcome.

Table 1- Summary of Issues in Achieving Capstone Objective and Outcomes Online

Objective	Outcome Issues	Issues Detailed Explanations
Objective 1	1.1 None 1.2 None	
Objective 2	2.1 None 2.2 None	
Objective 3	3.1 None 3.2 Coordination and procurement	a. Coordination and procurement of physically supplied and built components b. Performing system integration c. Performing validation testing
Objective 4	4.1 Team dynamics 4.2 Assessment and improvement	a. Openness and ease are slightly affected by the limited familiarity and physical interaction with other team members. a. Limited ability to observe, assess, and point out improvements to body language during oral presentations.
Objective 5	5.1 None 5.2 None 5.3 Physical build	a. Limited ability for build iterations and examining manufacturability alternatives. b. Limited ability for physical testing and validation

Discussions

In regard to the issues summarized in Table 1, whether these issues are related to the restrictions imposed by the COVID-19 pandemic or not, it is clear that these issues should be addressed to adjust for the differences between the face-to-face and online modes of the capstone course.

The online capstone course issues for objectives 3 and 5, are related to the different phases of the product realization process [18]. As illustrated in Figure 5, the Inception/Planning phase is perceptual in nature while the Conception/Design is virtual in nature. Both perceptual and virtual activities can be performed and educationally delivered in the virtual or physical domains. However, the Build/Manufacturing activities are physical in nature. Accordingly, special attention to technology, logistics, and coordination are necessary when planning and executing these physical activities from the perceptual and/or virtual domains. For online capstone courses, advanced technology such as additive manufacturing and computer aided facilities with enabled remote access discussed in [19, 20], may be needed to compensate for the limited physical mobility and interactions. In addition to these technologies, well-designed shipping and receiving processes along with precise coordination are necessary for successful management of off-the-shelf components and the final assembly/validation.

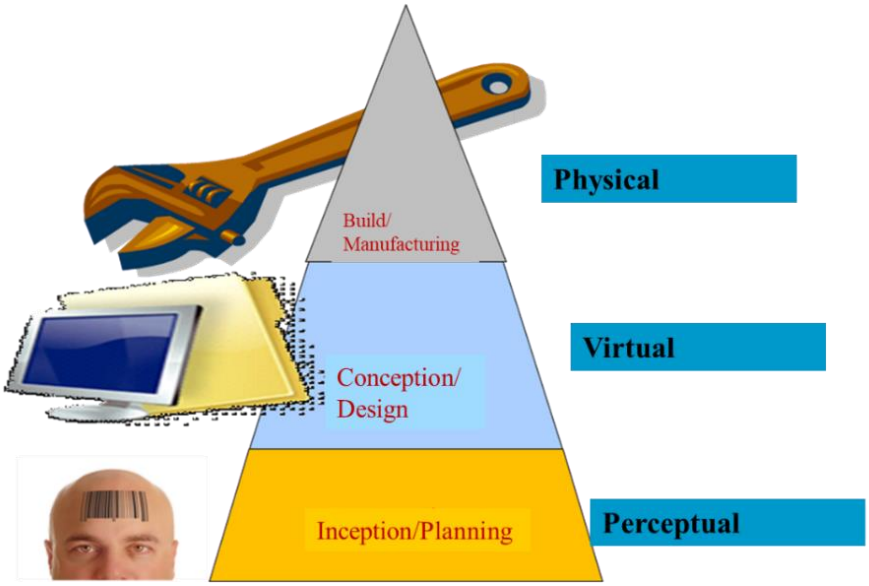

Figure 5 – Product Design and Development Phases [18]

To address the online capstone course issues for objective 4, the practice of teamwork and communication skills, a combination of the following approaches could be utilized.

1. To compensate for the lack of familiarity and physical interaction with other team members:
    a. Extra time for team building and interactions could be assigned.
    b. Long team meetings and breakout room discussions could be designed.
    c. Frequent communications and videoconferencing should be encouraged.

2. To enhance physical activities and body language assessment:
    a. Videotaping of team meetings and project physical activities could be encouraged.
    b. Self-taping of individual team members assigned presentations could be requested.
    c. Major team presentations should be rehearsed.

The suggestions for addressing the lack of familiarity and physical interaction with other team members may negatively impact student workload and increase the demands on students' time. This issue, however, is related to the restrictions imposed by the COVID-19 pandemic and social distancing. Without the restrictions, physical interaction with other team members could be resumed with an online format during normal conditions. As for enhancing physical activities and body language assessment, the suggestions made do not negatively impact student workload. It is normally recommended for students to record their meetings, physical activities, and presentations even for face-to-face format.

Conclusions

To provide a culminative, integrative, and open-ended design experiences as defined by ABET, a set of learning objectives and outcomes for project-based capstone course were established. These capstone course learning objectives and outcomes foster creativity, develops students' planning and management skills, and provides students with a comprehensive product development experience. These established learning objective and outcomes are implemented in a two-semester Mechanical Engineering Technology capstone course, with emphasis on the design phase in the first semester and physical build/validation phase in the second semester.

During the Winter 2020 semester, the physical builds of all the Mechanical Engineering Technology capstone projects were completed in online format, due to COVID-19 pandemic. Subsequently, during the Fall 2020 and winter 2021 semesters, the first semester design phase and the second semester physical build/validation phase of the course were complete in the online format with a new cohort of students. To achieve the course learning objectives and attain student outcome, during the online format, several issues were identified and addressed.

To address the online capstone course issues related to the physical build and validation phases, advanced technology such as additive manufacturing and computer aided manufacturing with enabled remote access are needed to compensate for the limited physical interactions. In addition, well-established shipping and receiving processes along with precise coordination are necessary for on-time delivery and successful assembly/validation. To compensate for the lack of physical interaction, frequent team building activities and conversations should be stimulated. Finally, for enhanced assessment, videotaping of team meetings and project physical activities should be encouraged.

Based on the assessments conducted for attainment of student outcomes and the evaluation of course learning objectives achievement, project-based engineering capstone courses could be successfully taught in the online format. In general, the quality of the projects and the final products developed by the students were at par with the face-to-face classes. In addition, the online format proved useful in building the virtual communication and team working skills needed for global product development and potential for industrial, academic, and multidisciplinary collaborations. Students' surveys and comments also indicated that the capstone online format would allow for

more flexibility, provided that the team physical interactions are not be limited to stimulate the team members' energy and enthusiasm.

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