Capstone Design - Unexpected Challenges and Opportunities due to the Covid-19 Pandemic

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Abstract

Due to the Covid-19 pandemic George Mason University (Mason), similar to many institutions, had to suddenly switch to online delivery of all courses in March 2020. As the director of senior projects (first author) for the mechanical engineering program, this forced me into an unexpected situation. As many other engineering professors can attest, teaching laboratory intensive classes and design courses adds additional layers of complexity within the online delivery mode.

The co-author who taught two other sections of senior design and the first author had to immediately devise a plan on how to continue to deliver a meaningful design experience to students online in the middle of the semester. While most programs in the country adjusted their capstone programs to face the unexpected pandemic, our program had its own set of challenges to overcome. The first concern for the authors was how to continue to provide a meaningful design experience to the students and the second one was how to complete the projects to meet the sponsors' expectations. That is why we decided to share our experience so we can generate more thoughts and discussions during the conference.

Our first effort was to use our extensive engineering experience to challenge the senior students. Access to the machine shop was not allowed beginning halfway through the spring 2020 semester. During a normal academic year, student teams perform much of the fabrication and testing of their prototypes during the spring semester. Since access to the machine shop was not allowed, the focus of the program shifted towards a greater emphasis on analysis and technical writing.

Another challenge is due to the model used for capstone projects at Mason in which 100% of the projects are externally sponsored by industry and government partners. In order to prepare the projects for the fall 2019 semester, authors worked side-by-side with the sponsors to agree on deliverables and top-level requirements in the preceding summer. Satisfying the needs of the sponsor, for nearly all projects, requires a significant 'hands on' component in terms of fabrication and subsequent testing. In prior iterations of the capstone course sequence, teams were expected to interface with the sponsors frequently, but the pandemic made sponsor-to-student interaction more difficult. We had to think of creative ways in which the student teams can meet the expectations of the sponsors who provided financial support.

With the assistance and approval of the department leadership, we adjusted the course learning outcomes to suit the "unforeseen design conditions" of the capstone projects and provided a real-life learning experience in project management to the 59 senior students enrolled in the class. Although the modality of instruction changed and the access to campus was prohibited after the campus closure, the student teams were remarkable in coordinating the teamwork virtually.

Because the students have worked together in teams before pandemic and knew their teammates, the aspect of teamwork progressed smoothly during the crucial early days of online learning in March 2020.

Via extensive planning and adjustments to the course content and delivery, we successfully completed the two-semester long capstone program which concluded with a virtual capstone day in May 2020. This paper provides details on how the capstone program adapted to the Covid-19 pandemic at Mason while maintaining a rich learning experience. We share our experiences from the 2020 spring semester, discuss how we continued to adjust and manage the capstone program for the current academic year (AY) 2020-21 with uncertainties and create a stimulating dialogue.

Background

The mechanical engineering (ME) program at Mason requires the senior students to successfully complete a two-semester long, Senior Design I and II courses as part of the curriculum for the B.S.M.E. degree. The two courses, worth three credit hours each, are known as the "ME capstone program." The ME program at Mason is young, having started six years ago and has already gone through a successful accreditation evaluation by a visiting ABET evaluation team. The AY 2019-20, i.e., the class of 2020 at Mason represents the fourth graduating class for this program. In addition to meeting the curriculum requirements, the capstone courses are required to meet the ABET [1] EAC Criterion 5(d) in providing a culminating design experience. The capstone program is managed by the first author, a designated faculty member known as the Director of Senior Projects (DSP) and all the student projects are sponsored by industry or government. After working in the industry for 30 years, this was the first year in academia for the DSP and this sudden transition was an unprecedented challenge for the DSP as much as it was for the students.

A substantial benefit to the students in working on a sponsored project is that they have a chance to solve a real-world problem and at the same time gain experience in project formulation, proposal writing, planning, analysis, design, fabrication, testing, communication and project management; skills very similar to those required of an engineer working in industry. In the previous years before the pandemic, these objectives were successfully met by the students. For the class of 2020 students, senior design instructors and the DSP, the pandemic presented "unforeseen" design conditions and unplanned circumstances and challenges that were not experienced in the past. Identifying and managing risks are part of any design process; however, none of us expected or predicted the possibility of the arrival of pandemic and sudden closure of campus during the AY 2019-20.

The current academic year, AY 2020-21 is different in many ways compared to the last AY. The academic year started with most courses offered online and only a very few (less than 10%) of the courses were offered either in-person or as a hybrid mode consisting of a mix of in-person and online delivery during the fall semester. During the spring semester, approximately 20% of the classes were offered in-person or in a hybrid mode of instruction. Greater emphasis was placed on teaching students how to manage project risks via leveraging video conferencing software and shared file systems.   The students were fully aware that the pandemic situation

could deteriorate anytime and change how they manage the project and collaborate with each other during the AY 2020-21 without adequate notice.

Literature Review - capstone programs at other institutions during spring 2020

Senior design courses in engineering take various formats at different institutions, anywhere from one semester to two semesters, single year to that evolving over multiple years, theoretical to those involving laboratory and machine shop use, and projects initiated by faculty or students to those externally sponsored. Therefore, how a program adjusted to Covid-19 varied across the country.

At Drexel University [2], material science engineering students did an in-depth analysis and completed a quad-chart type written report. Students from mechanical engineering, and electrical and computer engineering produced video elevator pitches to highlight their technical skills and creativity. The students also produced a written report reframing their experiences to focus on their successes.

At the University of California, Santa Cruz [3], the students in one of the teams were able to conduct limited experiments and numerical simulations at home. It was made possible because the engineering school let the team borrow a few vital pieces of equipment and students in that team utilized MATLAB from home to complete their project. In another instance, a team partnered with a graduate student who had access to the laboratory to download the data for the team so the students could analyze it from home.

The University of Cincinnati [4] conducted a capstone project showcase virtually on April 17, 2020 and posted a video presentation of their projects and answered questions live during video conference. In our case, the students presented their projects live and fielded questions, all done in a virtual team setting. In the authors' opinion, the aspect of teamwork remained strong at Mason during remote work as evidenced during the day-long virtual capstone symposium on May 12, 2020.

The Georgia Institute of Technology's biomedical engineering program [5] has been partnering with medical students beginning 2018 to work on multi-year projects to develop medical devices which could address global health problems. These projects focus on addressing clinical needs under resource limited settings and also faced challenges due to Covid-19. Although the projects span multiple years, they involve students at various class levels and one semester capstone program for senior engineering students. This type of model was helpful for them to overcome the Covid-19 closures with senior engineering students performing rigorous engineering analysis while working remotely.

As observed from cases at various universities, there is no "one size fits all" solution. The important attributes are being able to adapt and adjust the mindset, engineer solutions to varying realistic conditions, and provide a meaningful educational and culminating design experience.

This is what the authors tried to instill in our senior engineering students and thus the impetus for this paper.

Capstone projects at Mason during the academic years 2019-20 and 2020-21

The pandemic situation has varied across localities and states in the country. Due to proactive measures implemented by Mason, the pandemic situation remained almost unchanged or at a slight decline throughout AY 2020-21 as far as the infections rates and positivity of surveillance testing were concerned. That was good news for students in that they were allowed to come to campus to work in the machine shop on capstone projects with social distancing in place. The DSP managed to offer the capstone class meetings in a hybrid format during both semesters of AY 2020-21 and it has helped to keep the students engaged, motivated, participate in team activities in-person and productive.

Because the course was taught by the previous DSP during AY 2018-19, the first author did not have benchmark data to compare with 2019-20. However, the comparison of data of AY 2019-20 and 2020-21 is meaningful. Based on the student evaluation of teaching conducted by our university during the fall 2019 (in-person classes) and fall 2020 (hybrid format) semesters, the quality rating declined from 4.25 to 4.00, on a 1 to 5 scale, with 5 being the highest value. While a drop was expected, it was not significant and validates that the proactive positive measures taken during fall semester 2020 helped to maintain the culminating design experience for students. Further, the students were allowed to come to campus during the spring 2021 semester to work in the machine shop. Although social distancing measures were in place, with advanced scheduling our students have used the machine shop to fabricate and test their designs during the spring 2021 semester which ended in early May.

Changes in course learning outcomes and grading policy

For most undergraduate courses that have a typical lecture format, pivoting from in-person to online delivery is not a "drastic" change. However, courses that are heavy in laboratory use or design-oriented faced additional challenges. The ME Capstone program presented unique problems to both the instructors and the students because the university suddenly closed the access to facilities, laboratories, and machine shops during the second half of the spring 2020 semester. Instructors had merely two-weeks of time to transition to online teaching. The authors, as the instructors of senior design, also had the same two weeks to recalibrate the course learning outcomes such that the students can be reasonably expected to complete the remaining tasks in seven weeks without the ability to use the machine shop for any fabrication or testing of their design.

The capstone program meets two major requirements: The first one is the ABET [1] Criterion 5, Curriculum (d) "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 second requirement is the course learning outcomes of Senior Design I and II, that are mapped to the applicable student outcomes of ABET [1]

Criterion 3. The course learning outcomes (CLOs) for the senior design courses at Mason are shown below with the recalibrated CLOs in the last section during the 2020 spring semester.

Senior Design I (fall semester)
1. Develop a detailed design project proposal
2. Apply project management tool to establish goals, plan tasks, and meet objectives
3. Create system design, preliminary design and critical design reports
4. Present the project proposal and design reports to customer

Senior Design II (spring semester) pre-pandemic
1. Fabricates, integrates, tests and analyzes system performance
2. Applies project management tools to track progress
3. Documents final design process, the system, its performance and projected implications

Senior Design II (spring 2020 semester) with modifications after the pandemic
1. Theoretical analysis and validation of proposed design
2. Applies project management tools to track progress
3. Documents final design process, the system, its performance and projected implications

Students had started to work on all three CLOs of Senior Design II before the spring break and they had planned to continue their work after spring break, with a significant part of CLOs 1 and 3 yet to be performed. When Mason announced that the campus will be closed for the remainder of the AY 2019-20 and the teaching would be exclusively online, we were faced with uncertainties and anxiety over how to complete the senior projects. The authors in consultation with the department leadership, decided to modify the CLOs. For CLO 1, the student teams were asked to perform a detailed theoretical analysis and validation of their design. Further, based on their findings, the student teams were asked to form conclusions of their project and to recommend work for future continuation of their project.

Together with the recalibrated CLOs for the senior Design II in the spring 2020 semester, the authors revised the grading scheme for the course evaluation as shown on Table 1 to align with the new reality.

Table 1 - Grading Scheme Before and After Covid-19, Spring 2020

Original Grading Scheme	Modified Grading Scheme After Covid-19
Team Activity Reports - 15%	Team Activity Reports - 15%
Analysis and validation report - 20%	Analysis and validation report - 30%
Progress Report - 20%	Progress Report - 20%
Final Project Report - 25%	Capstone Brochure - 20%
Capstone Day Poster and Presentation - 20%	Virtual Capstone Day Presentation - 15%

Providing meaningful design experience during pandemic with increased emphasis on theoretical analysis and validation

The first concern for the authors was how to continue to provide a meaningful design experience to the students and the second one was how to complete the projects to meet sponsors' expectations. Based on the feedback from the students and sponsors, the authors successfully managed both concerns. Typically, the student teams perform fabrication, testing and validation in the machine shop. They were asked to perform more rigorous analysis than initially required and revised grading scheme reflects increased weight for analytical methods and validation. They were evaluated, still under a team setting, on how they managed to include additional analysis or more detailed design work, and verified their work presented as part of their critical design review during the previous fall semester. During a normal year, most of our students do not use the finite element analysis in their designs but this team had more time to perform a highly sophisticated analysis than originally planned. Figure 1 shows an example of a more rigorous analysis in the absence of prototyping and testing.
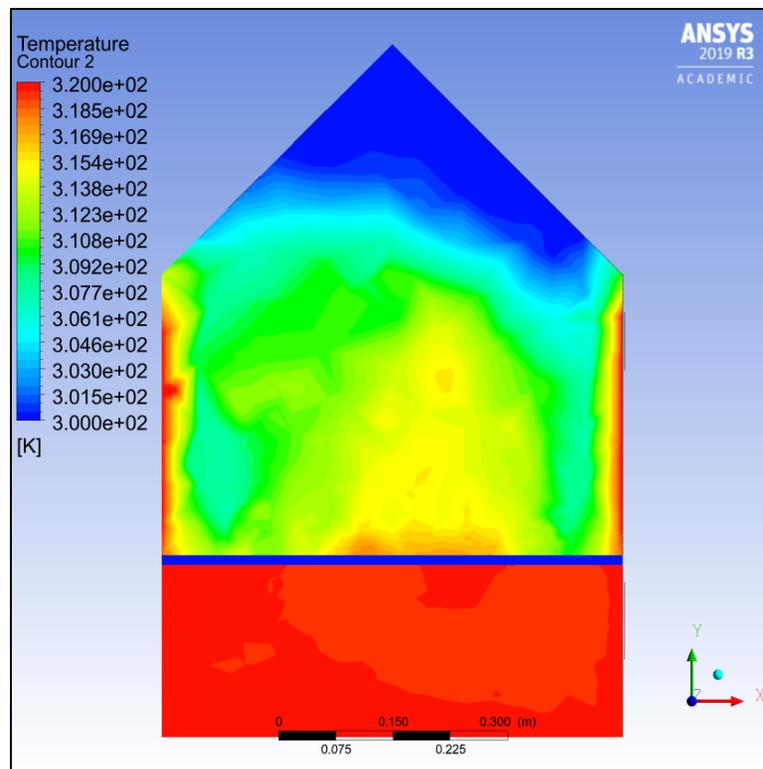

Figure 1. ANSYS Generated model of heat transfer inside a chamber

Instead of displaying their products with a poster during the traditional capstone day, the teams while remotely coordinating their work, made a presentation for 30-minutes during the virtual capstone symposium. It was apparent to anyone watching the presentations that the teams had functioned well as teams during the virtual environment. The revised grading system rewarded the student teams for additional analytical work, teamwork and presentation skills.

Potential adverse effects on ABET accreditation status

Another major concern for the authors was how the capstone final reports of AY 2019-20 would be viewed by a visiting ABET team in the future. The first author has 15 years of experience serving as an ABET program evaluator and currently serves as an EAC commissioner and as a team chair. During the evaluation for the 2020-21 accreditation cycle, ABET's guidance to evaluators was that programs would not be judged based on a program's response to Covid-19. ABET instructed the visiting teams to evaluate the program and its processes over the duration of the accreditation cycle for compliance with the criteria and not just over a snapshot in time representing the "sixth" year when the pandemic appeared. Knowing how a program adjusts the capstone program temporarily during an extremely rare event such as Covid-19 will have minimum effect on the program's accreditation is very important. As long as the programs continually strive to meet the ABET criteria during the standard six-year cycle, there should not be any adverse effect on the decision related to accreditation.

What would happen if the pandemic prevents the programs from executing a meaningful capstone program during AY 2020-21? If a program is unable to provide such an experience, in the eyes of a potential ABET evaluation team, it would have forgone two of the six years due to the pandemic and it remains to be seen how a program would fare if it were to be visited for evaluation by ABET during the fall 2021 semester. A program can make a case if it had provided and documented very extensive and excellent capstone experiences in four out of six years during an accreditation cycle. On the other hand, if a program waited for the last two years of the six-year period to demonstrate and capture a valid capstone experience, and if it were cancelled due to the pandemic or for any other reasons, then it would be very difficult to demonstrate that the program was in compliance with the ABET criteria. Based on the activities over the last two semesters, we can state that we managed to provide a meaningful culminating design experience under "limited access" conditions and social distancing guidelines during the AY 2020-21.

Teamwork and managing expectations

Even after transitioning from in-person to virtual learning, the authors continued to emphasize teamwork to students. All students continued to participate in team activities and meetings remotely without any reduction in productivity. Each team also continued to keep sponsors appraised of its progress periodically. The DSP frequently communicated to industry sponsors of the proposed changes and managed their expectations. The sponsors were very understanding of the public health situation and the restrictions imposed by the governor and the university. The authors requested that the student teams perform an in-depth theoretical analysis and validation of their intended design. All teams chose one or two critically important components

in their design and proceeded with a more thorough analysis in order to offset the prototyping and testing opportunities lost due to the pandemic. As the last deliverable, the teams submitted a final analysis and validation report which contained the aforementioned details.

In a typical academic year, the senior design is concluded with an end-of-the year "Capstone Day" where students display their creativity and final product with demonstrations and presentations to faculty, family members, friends, and sponsors. Although an in-person capstone day was not permitted in the spring 2020 and the graduation ceremony was postponed by the university, the authors wanted to provide the graduating seniors with a memorable experience by hosting a virtual event.

Very first virtual capstone day at Mason in May 2020

The authors organized a "virtual capstone day" in which each team was allotted 30 minutes to give a live presentation and answer questions to audience attending remotely. The virtual capstone day opened with remarks by the associate provost, the dean of engineering and the department chair. Then the fourteen student teams had seven hours to make their presentations and the day ended with a virtual celebration. The very first virtual capstone day was a success with over 150 attendees. Even the university president attended for an hour and was impressed with what was achieved despite the pandemic restrictions and gave a very positive feedback to the students.

Given the sudden and unexpected situation due to the pandemic, the students rose to the challenge, continued to work as a team in virtual environment, completed their projects as required and concluded with a successful virtual capstone event. The whole experience provided a valuable lesson to the students. In engineering design, things do not always proceed as initially planned. The program management process is a valuable tool but it needs to be dynamic and flexible to deal with unexpected changes. An engineer starts out with a particular design in mind but when the conditions change, the engineer must adapt and be nimble. The end-goal is to provide the customer with a useful product that is designed with safety in mind, adhering to engineering standards, while meeting all of the requirements. In our estimation and based on the feedback from other faculty members and sponsors, the capstone projects during AY 2019-20 provided the students a valuable real-world experience.

At the start of the fall semester of the current AY 2020-21, the authors were proactive and asked the student teams to factor in potential disruptions due to pandemic in their work planning with the possibility that the access to campus facilities could be denied any time without notice. Fortunately, the campus did not close during the AY 2020-21 but the facemask mandates and capacity limitations to classrooms and machine shop continued to remain in place. In addition to designing to meet engineering standards and realistic constraints, the students have been learning to manage additional risks posed by the unpredictable public health situation. Undergraduate students usually have an extended winter break between the fall and spring semesters and this year they were advised to be proactive and work on the capstone project during the winter break as an insurance against any potential campus closures during the spring semester 2021.

First Hybrid Capstone Days at Mason in May 2021

By end of April 2021, most of the faculty and staff members have received vaccinations and students were starting to receive their first of the two vaccinations. We hosted the first ever hybrid capstone display for two days in May 2021 with capacity-controlled attendance and socially-distanced participation. In the hybrid format, the students from 17 teams set up static displays with artifacts, videos and posters. The display was extended for a second day and only about 25% of the teams were present at any given time and the visitors were pre-issued timed tickets to limit the crowd. The students enjoyed showcasing their creativity and products to fellow students, faculty members, families and friends. By any measure, the hybrid capstone days were a huge success based on feedback by the attendees. Although the students could not produce to their maximum capacity in the machine shop due to pandemic restrictions, they had a very productive "culminating design experience" during the AY 2020-21. Those who visited and observed the displays during the hybrid capstone days thought the students performed to their full potential.

Conclusions

Using the data gathered and experience gained during the AY 2019-20 and AY 2020-21, the authors expect to have a dynamic discussion during the July 2021 conference. As stated previously, it was not feasible to arrive at any meaningful conclusion based on only AY 2019-20 data. Based on the productivity demonstrated by the students during the AY 2020-21, the impact of the pandemic was very minimal. The students adjusted to the restrictions placed and overcame the challenges with careful planning and coordination of activities in the machine shop. The major challenge during the pandemic was obtaining adequate number of sponsored projects during summer 2020 just before the start of the fall 2020 semester when most of the offices did not have any physical presence. Mason ME department is considering alternative methods to obtain external funding and/or to streamline how projects are vetted and mentored in future years. The authors are interested in knowing how the capstone projects are developed and funded at other universities to provide a culminating design experience to students. We expect this paper to generate an interesting discussion and to provide the audience with a choice of ideas to use in the future. A capstone program is after all an engineering project; expect the unexpected and be prepared to execute backup plans and manage contingencies. Anything else will not provide a true design experience!

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