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Making it Work in the Virtual Capstone Climate and Beyond: Project-based Perspectives Across a Variety of Programs and Universities

Dr. Shraddha Joshi, James Madison University

Dr. Shraddha Joshi is currently an Assistant Professor in the Department of Engineering at James Madison University. She earned her Ph.D. in Mechanical Engineering from Clemson University with her research focused on understanding the role of requirements in engineering design by novices. At Clemson, Dr. Joshi has worked on multiple industry sponsored research projects (Michelin tweel –low rolling resistance for non-pneumatic tires, IFAI ballast friction testing project). She was actively involved in mentoring and advising Capstone design projects. She has advised over 10 different design projects –BMW, Rotary, TTi and mentored over 100 students. While at Clemson, Dr. Joshi was also awarded endowed teaching fellowship as a part of which she has taught a sophomore class on Foundations of Mechanical Systems for 2 semesters. Dr. Joshi worked as a Post-Doctoral Fellow with Professor Jonathan Cagan at Carnegie Mellon University. She investigated the avenues of internet of things and connected products. While at Carnegie Mellon University, Dr. Joshi was also instructor for classes such as Mechanical Engineering Seminar, Capstone Design and Storytelling with Machines.

Dr. Joshi's areas of interest include requirements in design, conceptual design, engineering education, design representations, development of design tools and design research methods, internet of things and connected products.

Mr. Bob Rhoads, Ohio State University

Bob Rhoads currently functions as the Multidisciplinary Capstone Program Director for the Department of Engineering Education at Ohio State University. He has a Bachelor of Science in Mechanical Engineering from Ohio State University and Masters in Business Administration from Regis University. Prior to his involvement as the program director, he had over 12 years of experience in industry with roles that varied from process engineering to sales engineering to design engineering. He has also functioned as an engineering technology faculty for three years at Zane State College in Zanesville, Ohio, where he developed and taught courses that included CAD, solid modeling, statics, strength of materials, machine design, and statistical process control. He is currently active in curriculum development and education research focused on capstone design.

Dr. Kris Jaeger-Helton, Northeastern University

Professor Beverly Kris Jaeger-Helton, Ph.D. is on the full-time faculty in the Department of Mechanical and Industrial Engineering at Northeastern University (NU) teaching Simulation Modeling & Analysis, Human-Machine Systems, Facilities Planning & Material Handling, and Capstone. She is the Director of Senior Capstone Design in Industrial Engineering as well as the Founding Director of the Galante Engineering Business Program at NU. Dr. Jaeger-Helton has also been an active member of Northeastern's Gateway Team, a select group of teaching faculty expressly devoted to the first-year Engineering Program at NU. In addition, she serves as a Faculty Advisor for Senior Capstone Design and graduate-level Challenge Projects in Northeastern's Gordon Engineering Leadership Program. Dr. Jaeger-Helton has been the recipient of over 15 awards in engineering education for both teaching and mentoring and has been involved in several engineering educational research initiatives through ASEE and beyond.

Dr. Sindia M. Rivera-Jiménez, University of Florida

Dr. Rivera-Jiménez is currently a Lecturer at the Department of Engineering Education and an affiliate faculty to the Department of Chemical Engineering at the Herbert Wertheim College of Engineering, University of Florida (UF). In this role, she works towards creating evidence-based teaching practices for chemical engineering design courses and local and national community outreach activities. Her research focuses on understanding the processes that contribute to the persistence and retention of underrepresented minorities in academic engineering programs during formal and informal educational experiences. In particular, she is interested in studying collaborative environments, social perspectives and inclusive

practices in engineering design teams. Outside the classroom, she serves as a creator and facilitator of professional development workshops for industry and academia using blended instructional tools.

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Abstract

With all the changes in the educational landscape due to COVID-19, capstone design courses have been uniquely affected. With several transitions to virtual course delivery and/or hybrid models of learning, capstone faculty are now challenged with helping students meet project objectives and deliverables, fostering student team cohesion, and managing sponsor expectations in virtual settings, all while fulfilling the course learning outcomes. While there have been countless programs, communities, and support systems implemented to guide the transition to online teaching, initially there was very little available to systematically understand and support the capstone and PBL community. The objectives of this work are twofold. The first aim is to outline the challenges faced by capstone faculty due to transitions to primarily remote capstone offerings, particularly within the areas of managing sponsorship, completing projects, and producing the associated final project deliverables. The second objective is to open a dialogue to chronicle concerns, gather input, and share best practices across the broader capstone community. The overarching goal is to help overcome -and even rise to- these challenges. This research was conducted by capstone faculty at four different universities. The first phase of this initiative involved research to identify the issues and practices in the existing literature, especially relevant to virtual capstone offerings. The second phase of this research involved a survey of capstone faculty on this topic to reinforce and/or supplement the literature findings as the virtual circumstances evolved. To understand the acute challenges, the survey noted above was conducted with the broader capstone community to include a diversity of faculty associated with capstone at a variety of institutions. This included capstone directors, coordinators, instructors, and advisors. The third phase gathered information through a panel organized and conducted by the authors at the most recent ASEE conference while dealing with societal and academic COVID-19 restrictions. The ASEE panel served as a platform to bring together the capstone community for ongoing dialogue, supplying additional solution recommendations. Results from this research coupled with literature findings indicated the commonality of challenges faced by capstone programs regardless of timing, engineering major, program profile, or type of institution. Among the survey results were the following: (1) Due to COVID-19 conditions, 44% of the respondents reported complete cancellation of this event while 56% reported conducting some form of virtual exposition. The work represented in this paper supports an intention to be agile enough to adapt to any situation along this continuum - and likewise be posed to adjust when our capstone programs must react to emerging circumstances in the future.

Introduction

Capstone Design flourishes when teammates, clients, advisors, and instructors are face-to-face and are physically working hands-on at their sponsor sites and/or in the capstone studio together. This all changed when in-person connections and activities were no longer possible due to COVID restrictions. Many capstone programs were forced to adapt for the short-term, with little-to-no opportunity to plan. It then became apparent that the future capstone profile would require appreciable reframing to comply with ABET, offer students rich, rigorous and educational capstone experiences, and meet the needs/solve the problems of capstone sponsors. These conditions now require capstone faculty to be even more agile and innovative, not only to find solutions to the academic situation, but also to deliver for clients, appropriately challenge our students to be problem solvers, and serve as role models in how we address such challenges. The focus and the mission of capstone leaders is to maintain the quality of project deliverables and the integrity of client/sponsor relationships while still offering the capstone experience and meeting program and ABET Objectives.

In many ways this is a chance to be creative, embrace the currently evolving and newly emerging technologies, and rethink some legacy protocols. Vander Ark (2020) notes “Large integrated projects build agency—the knowledge and confidence that you can contribute.” [1] These projects teach project management, research, problem solving, writing, and presentation skills. Team projects develop collaboration skills and learners will have the opportunity to gain experience in remote working and the use of modern tools. It also should be noted that the concept of virtual projects and deliverables is not new. Virtual product development is not a recent emergence. [2] Until recently this has been unexpected and now it has become necessary.

Selected Capstone Success Factors. Several key factors that have been found to contribute to capstone success warrant extra attention when the conditions dramatically shift. These relate to project acquisition, teamwork and collaboration, communication, project management and agility, quality deliverables, and measurable results. Volumes have been done on teamwork and leadership as the foundation of Capstone, which, while not the focus of this work, are worthy of mention. When circumstances require dramatic adjustment, teams are asked to pull together for the project. Likewise, capstone leadership and project advisors each play an essential role in mentoring and leading by example. In addition, much has been written on the value of communication in capstone [3]–[5] , and this is exceptionally important in changing times. Finally, a key source of innovation opportunities inherent in capstone involves being able to successfully cope and pivot in the face of challenges and unanticipated setbacks. [6] While the main scope of this initiative is delimited to client relationships and project deliverables, each of these primary factors are woven into this work.

Understanding Capstone Challenges in the Virtual Setting. Projects in engineering serve as a way for students to integrate the "academic with the practical" and develop essential skills for their future work as engineers. [7] By its nature, capstone is the culminating form of problem-based learning (PBL). PBL is a student-centered approach based on activities designed to solve a particular problem as a stimulus for learning. [7] PBL addresses curricular needs for fundamental knowledge, skills and competencies applied to real-life problems and societal needs required by the engineering practice. [8] An essential role of PBL is the development of various professional competencies such as communication, teamwork, conflict resolution, leadership, and interpersonal skills. [9] During face-to-face instruction, coordination of design projects and PBL can be considered a relatively straightforward effort. However, as conditions transitioned into a virtual format, coordinating design efforts for both faculty and students presented a daunting challenge given the lack of close physical proximity, insufficient time to emend, and uncertainty of adequate online tools to support remote PBL practices.

Teamwork Effects. For the purpose of the current work, virtual teams are defined as ‘‘small, temporary groups of geographically, organizationally, and/or time dispersed knowledge workers who coordinate their work, mainly with electronic information and communication technologies to carry out one or more organizational tasks’’. [10] Virtual teams are common in global industries where new products are introduced and developed via the collaboration of employees who are not co-located. [11] There is evidence that electronically virtual capstone teams have been used successfully in engineering since the early 2000’s. [11] Previous work with remote engineering capstone design teams shows the need for tools that facilitate centralized mechanisms for document sharing, communication, and team collaboration. [12]

Communication and Interaction. A longitudinal study of multi-university, multi-disciplinary engineering capstone projects with virtual team members involved in product development projects highlights the importance of selection and use of communications tools. [13] This work found that depending on the project stages, virtual team collaboration should emphasize rich communication mediums (e.g., in-person remote kick-off meetings), tools for individual work accountability (e.g., in-person web conferencing and shared data editing tools) and, if possible, shifts from digital work to physical work (e.g., texting and in-person meetings). For these purposes 'in-person' means possessing a face-presence in electronic meetings and events. Major challenge for students' adoption of new tools seems to be the unfamiliarity with technology, especially if the tools are pre-selected by their instructors and initial reluctance to be seen online in more formal settings. [12], [14] In other studies, students on virtual capstone those who identified project management challenges included communication issues related to time zones and tools, scheduling meetings particularly with large size teams, lack of cohesive team identity, difficulties in peer reviews, logistical problems during prototype construction, and inconsistency in the project experience. Other problems encountered related to the lack of face-to-face interaction, unstructured course management, low team cohesion, and issues with team reporting. [11], [15]

Benefits and Workable Methods in Virtual Capstone Conditions. On the other hand, in his work on virtual capstone by design, Goldberg and Howe found that some teams identified broader benefits associated with this remote type of collaboration. [11] In this work, the authors indicate that students participating in virtual teams identified benefits such as improved communication skills, increased trust in their teammates when working remotely, improved personal and professional growth, increased value of team diversity in proposed solutions, and better relationships with instructors. More recently in 2020, Goldberg lists a variety of solution options for distributed teams. These include identifying safe makerspaces, configuring home test equipment, finding, receiving or making prototype parts, acquiring their own prototyping tools, and relying more heavily on simulations and design software. [16], [17] For example, students at UC Santa Cruz creatively commissioned a graduate student to access their Engineering Lab to remotely access materials and conduct tests under their video guidance and SoPs. [18] It is important note that there are inherent opportunities as well as challenges in the new essential virtual paradigm.

Motivation

With the advent of all-virtual instruction, an abundance of support was offered up across the educational community in the form of webinars, panels, programs, presentations, workshops, focus groups, online videos and articles, advice columns, and other. However, the unique features of capstone were not entirely met by the support initiatives offered. Even those addressing online labs and projects could not capture the unique challenges of capstone, particularly those that span multiple terms and have clients and sponsors in addition to coordinators and advisors. The team of four authors across four different universities joined efforts to unite and support the capstone community in this area. The particular focus, thus was primarily on sponsorship and clients as well as realizing final deliverables with both educational and practical value.

Faculty have reported that their efforts on blending old and modern teaching pedagogies after COVID-19 disruption profoundly impacted course delivery modalities. [19], [20] Compared to a regular course, engineering capstone design has additional PBL pedagogy and distinctive project management challenges. As noted above, in addition to fulfilling the course learning outcomes, capstone faculty are now challenged with meeting project objectives and deliverables, sponsor expectations, *and* the need for student team cohesion all while fulfilling the academic objectives *and* meeting ABET criteria. Moreover, the faculty approaches may differ depending on the engineering discipline, team composition (e.g., interdisciplinary), and how the long-term projects are scoped (e.g., faculty or industry-led). This work intends to provide insight into how capstone design faculty coped with the transition and adapted their capstone models after drastically changing course delivery modalities.

Methodology

Research Questions. The Design in Engineering Education Division (DEED) provides access to faculty directly involved in finding "new approaches and effective pedagogy in the area of engineering design education." [21] The division also provides a "forum to identify problems and needs in the area of engineering design education and explore the means to address those problems and needs." [21] Therefore, the following research questions were formulated to disseminate best practices to the engineering design education community:

1. What are the challenges that capstone design faculty faced during remote instruction?
2. How did those challenges impact the way faculty teach and approach capstone design?
    a. What adaptations have been made successfully to address the primary challenges?
    b. What advice can be provided to faculty who are facing those challenges?

Survey Tool. To answer our research questions, a survey was developed and conducted with the broader capstone community. As noted above, the survey intended to gain insights into the nature of challenges specific to the capstone community during the quick transition into a virtual format. Furthermore, the authors wanted to capture and share solutions, modifications, and recommendations that the capstone community made to adapt in an agile way.

The authors designed the survey to include 27 items divided into four broad categories unique to our capstone community. The questionnaire included a mixture of contingency-driven, multiple-selection, and open-ended questions. The selection of descriptors for this survey was based on the authors' combined long-standing experience within the capstone community and was piloted for clarity and inclusiveness. In addition, the open-ended questions and associated options were provided to obtain any unforeseen input from the participants. A sampling of the questions used is included in Appendix A of this paper and the four categories of inquiry are outlined here:

- The first category included gathering basic demographic information such as institution type, engineering discipline, nature and length of capstone projects, and the participant's role. These questions allowed the authors to get demographic context for the responses.
- The second category of the survey focused on sponsorship and related issues due to COVID-19. These questions were intended to capture potential changes in the contractual agreement with the sponsor, potential changes in the meeting project deliverables, and managing and planning future sponsor expectations.

- The third category of the survey aimed to collect information about potential teams' challenges after going into a virtual format. This facet is not addressed in this paper, but yielded rich results and will be covered in a future publication.
- Finally, the last category of the survey collected information about potential challenges for teams meeting project expectations by including questions about changes in final deliverables as well as changes to capstone events.

The majority of survey participants were members of the capstone community from the American Society of Engineering Education (ASEE). The targeted survey respondents included instructors, advisors, coordinators, mentors, and directors. The survey tool was distributed via the ASEE DEED email list and various professional contacts of the authors through their broader capstone community. The data was collected between May and June of 2020. Participants were notified that the data from the survey would be used anonymously and aggregated for publication to share the findings with the broader community.

Panel Session and Dialog. In addition to the survey, a Design in Engineering Education Division sponsored panel session was conducted at the ASEE Virtual Annual Conference in June 2020. The panel designed and led by the authors was well-attended and focused on three broad topics, two of which are also the focus for this paper. Related to virtual capstone conditions, these topics included 1) Managing capstone sponsorship, 2) Fostering teamwork and student connection, and 3) Reimagining prototypes and deliverables. The goal of this panel was to start the conversation to identify adoptable ideas for the current and near-term capstone offerings in a virtual environment. The panelists curated the data from the survey to present during the panel, and to catalyze a rich conversation focusing on lessons learned, solutions and best practices. Each panelist spoke about a topic for several minutes and remaining time was allocated for questions and answers, chat commentary, and open discussion. The panel also provided opportunities to connect with capstone personnel from a variety of other institutions.

Collaborative Document. In addition to conversations during the panel, a shared document was crowd-sourced, created, and shared during the panel and beyond for participants to post and respond to questions and suggestions from other attendees. This shared document became a rich source of information for everyone. A table of resources curated from the literature findings, the survey responses, and the panel-generated document is included in Appendix B of this paper.

Results

A. Demographics of Respondents.

A total of 62 participants completed the comprehensive survey. To capture the respondents' work environment types, they could select any and all of the descriptors that applied to their institution. As shown in Figure 1, the options included private university, public university, small liberal arts college, technical schools, community colleges, mainly research focused, mainly teaching focused. To capture any unforeseen option, participants were also allowed to add any other option of their choosing. As shown in Figure 1, public and private institutions described most of our participants leading with 47% and 25%, respectively.

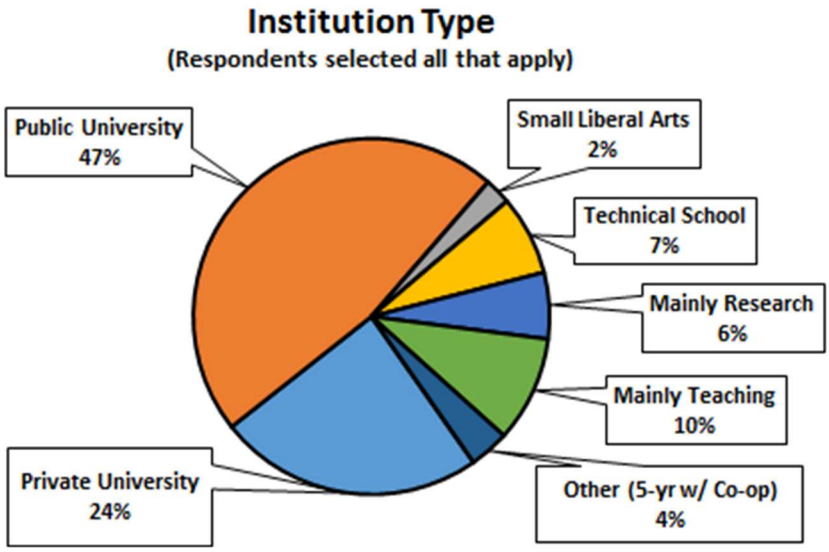

Figure 1. Respondent Institution Type

The survey also included the respondent's role(s) within their respective capstone programs. The respondents were able to select all of the descriptors that applied to their role. As shown in Figure 2, the descriptor options included Capstone Instructor/Coordinator, Capstone Advisor, and Capstone Project Sponsor. To capture any unforeseen option, participants were also allowed to add any other option of the choosing.

Figure 2 shows most respondents identifying themselves as either the instructor/coordinator of the class or advisor of projects. The "Other" category (7% of participants) included roles such as project recruiter, director of development, and communications instructor. These "Other" options provide information about the diversity of roles within our dedicated capstone community. These results may inform future researchers when drafting demographic questions in their own surveys.

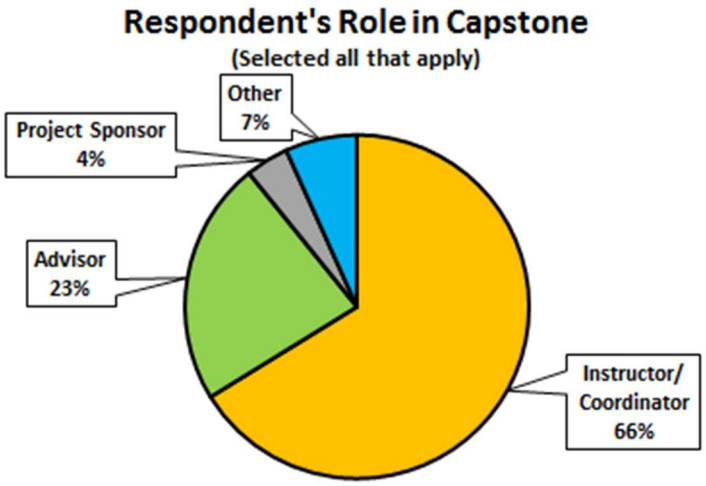

Figure 2. Respondent Role in Capstone

Respondents provided information on the length of their capstone offerings by selecting the number of academic terms. As shown in Figure 3, the vast majority of the respondents indicated that their capstone courses included multiple terms whether the institution was on the semester or quarter systems. Only 20% of the respondents indicated their capstone occurs in a single term or semester. Differences in the number of terms can potentially result in different experiences while transitioning into the virtual format due to the extent and pace of projects.

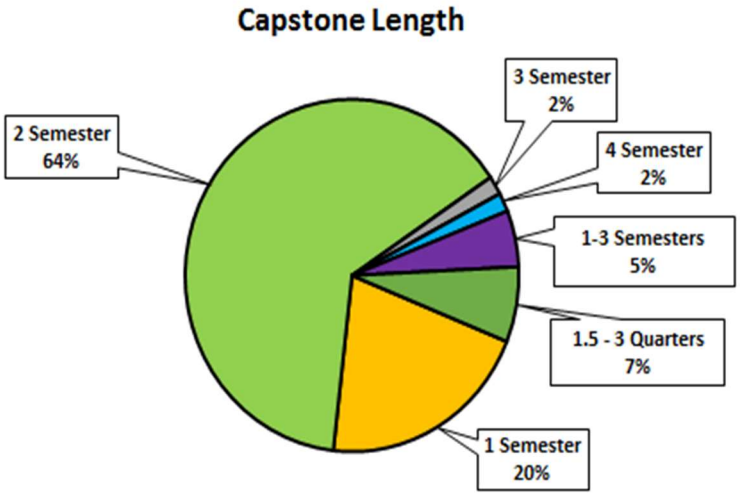

Figure 3. Capstone Length

Respondents were also asked to identify which engineering departments/majors participated in their respective capstone programs. The results showed that many capstone programs included students from several departments or programs. **Figure *4*** represents the distribution of different departments' participation. The "Other" category included such programs as engineering leadership, food engineering, global health technologies and manufacturing engineering.

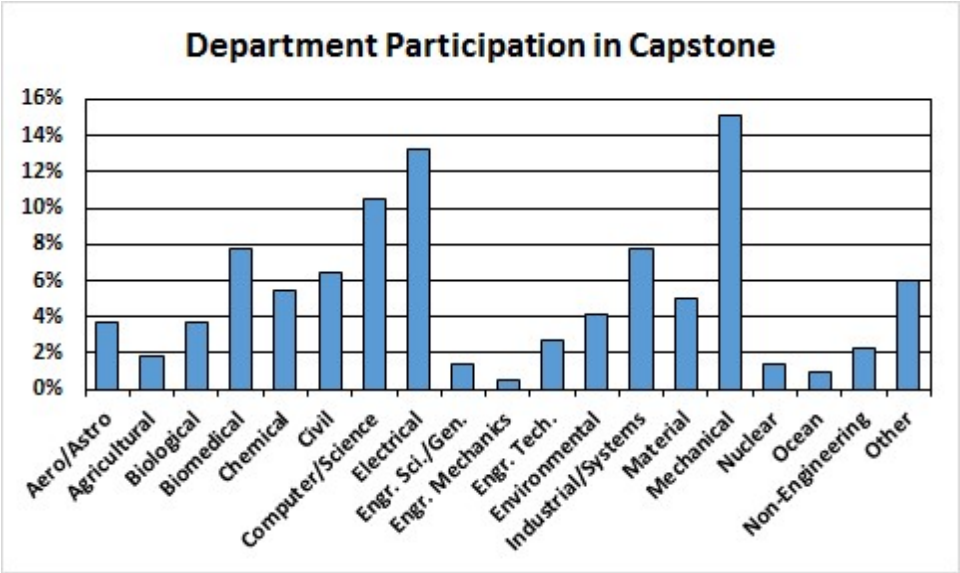

Figure 4. Department Participation in Capstone

The survey also collected information regarding the source and/or nature of capstone projects. The respondents indicated that they typically receive project topics from a variety of sources ranging from faculty, industry, the local community, research, educational areas, research centers, students, and competitions

Figure 5 shows a more detailed representation of these results.

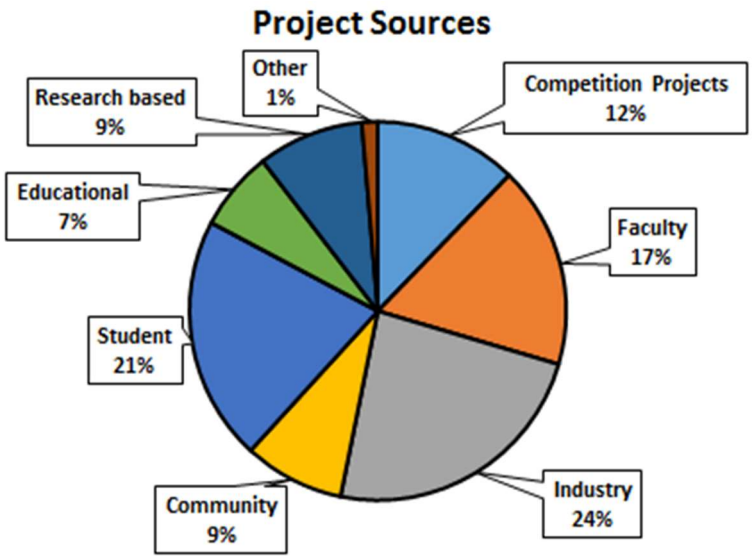

Figure 5. Project Sources

In summary, the respondents can be mostly classified as engineering faculty (e.g., instructors and advisors) managing multiple-semester capstone design projects within the university setting (e.g., public and private). The project sources seem to be mostly industry-based, faculty-led, and student-developed.

B. Sponsorship and Related Issues due to COVID-19

Sponsorship Contractual Agreements. Many institutions execute some type of contractual agreement with capstone sponsors. The primary purpose of this agreement is to identify terms of intellectual property, sharing of information, confidentiality, funding, project scope and deliverables to name a few. In addition, terms of operation may be included, such as data access, contact persons, as well as time investment and proposed duration of project. From the survey, 70% of the respondents indicated that their institution implements some type of contractual agreement or memorandum of understanding with capstone partners. **Figure 6** shows the results of this question.

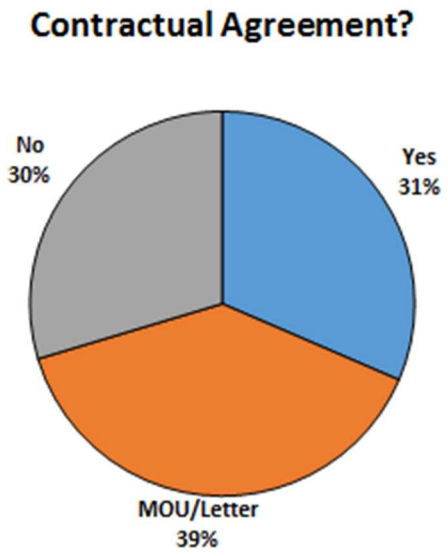

Figure 6. Sponsor Contractual Agreement

Meeting Contractual Agreement Deliverables. When working with capstone sponsors and agreements, project objectives are defined early on in the capstone project launch process. With the changes and adjustments necessitated by the COVID pandemic, capstone faculty and student participation were markedly altered, which affected the prospects of meeting project objectives in their initially envisioned form. *Taking into account the typical adjustments and rescoping that invariably occurs in the course of the capstone experience, survey respondents indicated that 57% of the projects did not meet the inceptive sponsor project objectives as they specifically relate to the compulsory shift to virtual conditions.* Figure 7 below displays these binary results.

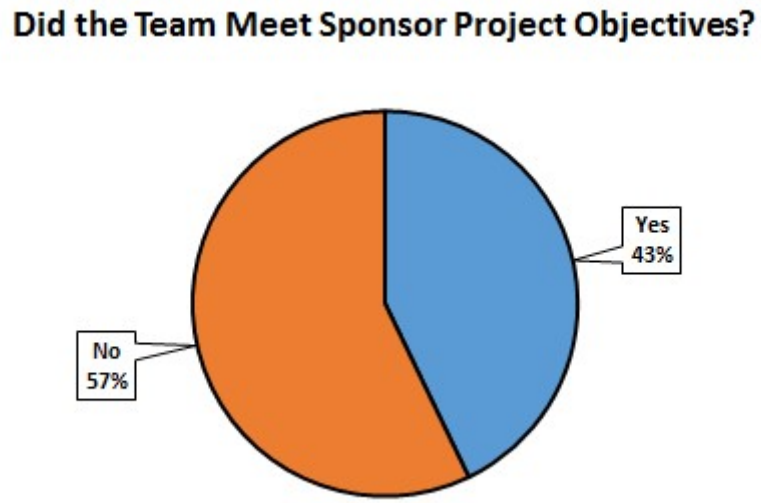

Figure 7. Meeting Project Sponsor Objectives

Challenges with Sponsors and Realizing Deliverables. Survey respondents identified many challenges when working with sponsors during this particular time period. **Figure *8*** represents some of these challenges. These challenges include such things as decreased sponsor, student and faculty engagement, and some incongruity of sponsor expectations related to agreements and project deliverables. *Engagement adjustments by stakeholders were observed to be reduced sponsor participation, students connecting to sponsors, and faculty engagement. Meeting sponsor expectations was a challenge through partially completed projects that did not meet contractual agreement objectives. Other related challenges encountered were access to campus facilities and the need to adjust project scopes due to these restrictions.*

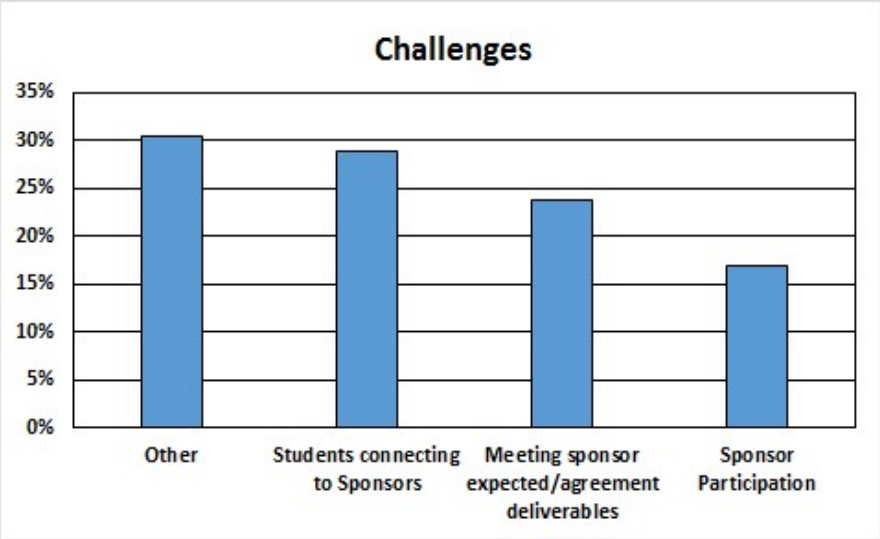

Figure 8. Primary Capstone Sponsor Challenges

Partnering with Sponsors - Recommendations. Survey participants were asked to provide suggestions and their own recommendations on how to address some of these challenges when working with capstone sponsors. The main themes from these responses include immediate and responsiveness and ongoing communication, project flexibility, and managing expectations. Open lines of communication with sponsors is critical to the success of capstone projects especially during challenging times. Whether the communication is between students and sponsor or faculty and sponsor, this connection is critical to an ongoing partnership as well as maintaining a common project path. Respondent suggestions to support this theme include having frequent/open virtual meetings with sponsor, faculty and students, implementing periodic project review boards with alumni to convey encouragement to students and requesting additional sponsor contacts to support the project.

Project flexibility is important in times of change. Being willing to adjust project scopes, deliverables, or timelines can be beneficial to all stakeholders. In addition, reassigning student team tasks and responsibilities or converting a physical to a virtual prototype can have an impact on the success of the project. The final theme from survey respondents related to expectations. With increased communication and flexibility, adjustments can be made and agreed to through contractual agreements or memoranda of understanding to accommodate uncontrolled

challenges. These adjustments can include no-cost extensions or contractual language to address potential situations like COVID19. Other suggestions to increase the success of projects include working with past sponsors and having dedicated students and capstone staff.

C. Project Deliverables Findings and Comments

Typical final deliverables in capstone courses include a prototype or demo (either a tangible product, a process model, a research outcome, or a digital program or design, depending on the nature of the project), a final presentation typically delivered to broader audiences, and a final report. Others' included poster sessions, demos, awards, and site visits. In addition to these final deliverables, most capstone courses have a final event such as an exposition, allowing students to showcase their projects to broader audiences. *Due to COVID restrictions, when classes moved to a virtual setting, many of these deliverables were not only affected, many were compromised.* Figure 9, shows deliverables affected due to virtual transition.

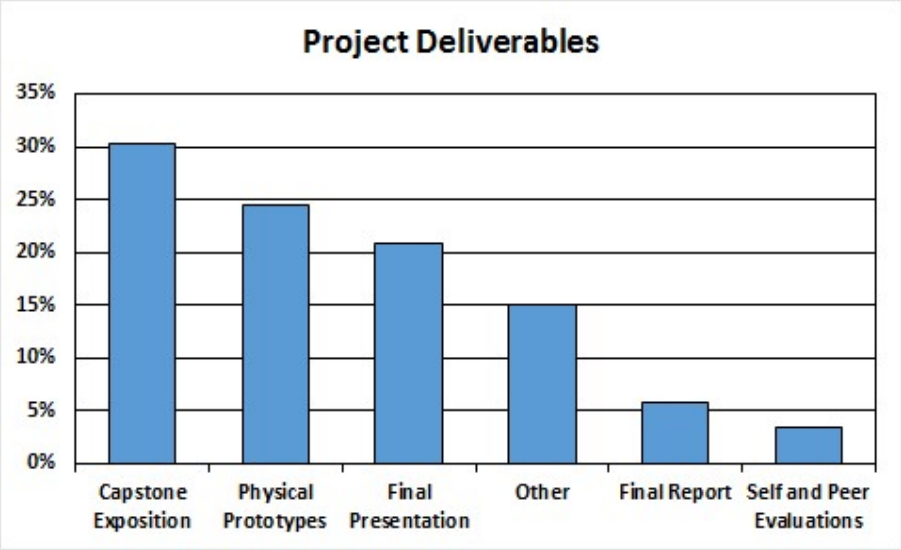

Figure 9. Project Deliverables across Capstone Programs

As can be seen from the chart above, the top three deliverables to be affected due to COVID conditions were capstone exposition, final prototypes, and final presentations, while those that were least affected were self and peer evaluations and final report. Some other deliverables that were affected but not listed here include poster sessions, demonstrations, awards, and site visits.

Changes to Final Presentations. For nearly all capstone projects, teams deliver a final in-person presentation at the end of the project to demonstrate the process and outcomes of the project. After going virtual, some of the final presentations were conducted in live virtual sessions using platforms such as Zoom or Teams. Typically, these presentations were either limited to the faculty and judges, or in some cases were open for invitees or the public to attend. Another strategy used was pre-recording the presentation and making them available for review by faculty, sponsor and/or judges. While these changes allowed students to present their outcomes to faculty, sponsor, and judges, they missed out on attending presentations of peers. From the survey results, it appeared that transitioning presentations to virtual environments was

quite workable compared to some other final deliverables. *At the same time, much of the tradition, competition, excitement, and energy of the final capstone showcase was lost.*

Changes to Physical Prototypes. Another deliverable that most capstone teams have as the culmination of the project is a prototype. For most of the teams this is a physical prototype, however, depending on the major this could also be digital prototype or other intangible. A*fter going virtual, the teams lost access to university facilities such as machine shops, prototyping studios, and certain software programs. These changes made it challenge to be able to complete the prototypes.* Several strategies were used by the faculty to accommodate.

These strategies can be broadly categorized as the following:

1. *Complete elimination of prototypes:* The most extreme strategy used was to remove the requirement to deliver a physical prototype. Only one faculty reported using this strategy.
2. *Partial completion of prototypes:* Partial completion was another strategy. This was done in several ways such as allowing for partial prototypes to be submitted, transferring parts to "supporters" to complete prototypes, moving completion of prototypes to the next semester, adjusting requirements for some teams unable to construct their prototypes, or letting the machine shop staff complete the student prototypes.
3. *Alternative prototypes:* The third strategy used by faculty was having alternative deliverables. These took the form of either modifying requirements to adjust for teams who could not complete prototypes or giving students other options to submit their projects. For example, instead of completing a physical prototype, students could submit a CAD model or virtual prototype or submit an ePortfolio including their design project or create a website about their design. In some cases, the students were required to do CAD simulations to test their prototypes.
4. *Video demos or screencasts*: If a team was able to create a solution that could not be experienced in person, a video or screencast of a working prototype or system proved to be quite effective.

Changes to Capstone Exposition. One of the other key culminating events for capstone classes is the final capstone exposition where students present their final designs. Typically, this exposition is held for showcasing capstone projects to the broader community, judges, and invited guests as well as current and potential project sponsors. It provides an important opportunity to the students to demonstrate their projects and is often a celebration of their hard work and efforts. *Due to COVID conditions, 44% of the respondents reported complete cancellation of this event while 56% reported conducting some form of virtual exposition.* There were some variations in how capstone was conducted virtually. In some cases, the expo was simply transitioned to a virtual environment (such as Zoom) where students would present their projects and prototypes virtually. This was either done live or pre-recorded. In some cases, the expo was open to the public while in other cases it was limited to faculty, judges, sponsors and invitees. Another example of change was having a week-long event with one hour of presentations each day at noon. This was followed by voting of awards at the end of each day. Some virtual expos also allowed for time at the end of presentations for casual conversations and discussions including networking, connecting, and meeting judges and other attendees.

The participants reported that while there were some disadvantages to the virtual expo, some benefits were also realized. *The drawbacks of the virtual capstone expo included not being able to physically interact with various teams and their prototypes, students missing out on seeing the projects of their peers and limitations due to online platforms.* However, due to the expo moving online, more people were able to attend. The faculty were able to engage alumni who were not local and who would normally be too busy to attend the regular end of the year expo in person. In some cases, over 700 people attended the virtual expo from different parts of the country. This allowed students to showcase their work to much larger audiences.

Recommendations

Several strategies that have emerged through this work are outlined in the following section. The strategies are framed from the coordinator, instructor, faculty, and/or advisor perspective working with capstone programs. The recommendations are based on the findings from the literature review, responses from the survey, input from the DEED panel, and the experience of the authors in their own capstone programs. We address the common challenges that have been identified as well as the most effective and generalizable solution options going forward.

1. **Model composure and rational optimism.** A calm positive outlook based on sound engineering, professionalism, and an innovative mindset will set the tone for all. The students will often follow your lead when it comes to perspective. If you respond with alarm and disappointment, students will likely follow suit. Alternatively, if you are calm and even welcome the uncertainty and the opportunities to be creative, they are more likely to adopt a similar perspective.
2. **Set the stage.** Cultivate and foster adaptability from the beginning with students, advisors, and clients. As noted in the introduction, it is well established that uncertainty and unanticipated situations will emerge. Create a culture of agility in this regard. Convey to the students that they can expect changes, adjustments and even major setbacks in their projects. Their success is not measured solely on the deliverable, but also on successfully adjusting and redirecting as is fitting.
3. **Get out in front of it with a flexible and responsive mindset.** Practice focusing on problem prevention through identification and anticipation. Conducting a SWOT analysis is a valuable exercise to help teams envision challenges and potential solution approaches in advance. [22]–[24]
4. **Be proactive with contingency planning.** Having teams write contingency plans and alternative solution paths has been helpful to get them into the solution frame when things change. This can be done as soon as a threat is detected. Business continuity plans are used in industry to outline how an enterprise will continue operating during an unplanned disruption in service. [25] Adopt and apply a capstone version of this tool. This could involve asking the sponsors for a list of deliverables they would accept if the students cannot complete a physical prototype. Examples may include design analysis, video walk-throughs, measurement and demonstration platform building, elevator pitch presentations, risk analysis, alternate designs, etc.

5. **Communicate consistently, clearly, and concisely**. Keep all stakeholders -teammates, advisors, sponsors, coordinators- informed on a regular basis and make it clear whether action or response is required. This communication can take the form of virtual meetings or periodic review boards with sponsors and alumni. Corresponding even in the absence of new information is appreciated more than silence, even without available updates.
6. **Involve everyone in the adjustment**. Coordinators, instructors, advisors, sponsors, and students alike can contribute to a new problem formulation as well as potential solution paths. Adjustments to project scopes, project milestones, and deliverables can be beneficial to all as long as everyone is involved in the discussion.
7. **Focus on building a community.** Fostering a sense of community and belonging becomes more important in virtual environments or those undergoing radical changes. This can be done by allowing time for team building activities, regular check-ins with students, providing opportunities for peer discussion and feedback.
8. **Focus first on functionality and usability**. Add complexity later. A highly complex solution proposal is of little value if it is not working or if sound proof-of-concept has not been established. Address needs before attempting to incorporate wants.
9. **Plan to be adaptable.** Select projects that are somewhat amenable to virtual format (not 100% prototyping). Include projects that have CAD, simulation, or phased components.
10. **Recognize that the internet can be your toolbox.** There are countless free versions of applications and tools, used for team formations, collaboration, communication, and project management, to name a few. These tools can be searched by using key words such as virtual collaborative brainstorming, project management, online prototyping, for example. See Appendix B for a subset of tools that were available and recommended at the time of the 2020 ASEE panel.
11. **Innovate with video.** Create recordings when on-site and in-person visits are not possible. Also, when physical demos are not feasible, students have created screencasts and/or demonstration videos to show their deliverable solutions in action. There are also tools found online to help create demons and visualizations. See Appendix B.
12. **Do not abandon testing and evaluation and/or value proposition.** Whatever is delivered is assumed to have value. Establish the metrics associated with that value and work to capture those, even if only in a modified way or by conveying ROI when applicable. For design-build projects, outline the engineering expertise contributing to the final design. Simulations are extremely valuable contributors for demonstrating value.
13. **Formulate an amazing hand-off.** If, for valid reasons, a full solution cannot be realized, a considered and intentional decision should be made to first deliver all that is possible and complete. Equally, set a focus on the next team or individual to take over the project through clear documentation, descriptions, and an outline for next steps. A quality turn-over outline shall serve as a key component of the deliverable.
14. **Appropriately adjust grading criteria** and communicate the prospect for reasonable modifications as early as possible. With the testing noted above, generate adapted design validation metrics and modular milestones to help you uphold capstone goals and ABET objectives while students can continue to innovate. You can still maintain standards while minimizing anxiety about the grade.

Conclusion and Call to Action

This work aimed to identify and gauge the fundamental challenges facing many capstone programs in the face of COVID restrictions and learn of the adaptations that were made for short-term management for courses that were already in progress. This work outlines patterns in best practices and lessons learned and gathers options and innovations for adoptable solutions, policies, and methods that may well be retained going forward.

We consider the following prospects on a continuum of future capstone profiles: fully remote capstone on one end, hybrid profiles in the middle, and capstone conducted completely in person at the other end. We initially mused: How can we be agile enough to adapt to any situation along this continuum -and likewise be poised to adjust when our capstone programs must react to emerging circumstances in the future? Answers were sourced from the collective capstone population.

Finally, a goal was to bring the broader capstone community together for an open conversation -- to connect, share concerns and challenges, and then to provide support through dialogue and by sharing suggestions, ideas and successes. The foundation for this work started with personal experience and empirical observation and a desire to expand the support system. The literature supplemented the list of known challenges and outlined opportunities to be embraced during transition to the virtual setting. Finally, the survey and the panel each provided rich sources of information to set the stage for a comprehensive collaboration network among the capstone community. Crowd-sourcing through national and international capstone supporters has delivered a set of ideas, options, and solutions, and further built community.

Many of the recommendations in the numbered list above can be adopted going forward regardless of the course delivery mode, major, setting, or product form. In the abrupt transition to virtual capstone conditions, capstone leaders and stakeholders made the pivot, demonstrated agile thinking, reflected on lessons learned, and have adeptly identified best practice for future capstone offerings. This work could not be accomplished without these dedicated and responsive practitioners.

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APPENDIX A: SURVEY QUESTIONS

Link to the survey: http://jmu.co1.qualtrics.com/jfe/form/SV_9SojnRYPkoCNg5U

Relevant sample questions from the survey:

Demographic questions

- Which option best describes your institution?
- What is your role in the capstone course at your institution?
- What is the length of academic terms at your institution?
- What programs/departments participate in your capstone course?
- What is the nature of the capstone projects at your institution?

Sponsorship questions

- How did you handle the project NOT meeting the agreement objectives or deliverables with the sponsor?
- How did you manage or plan to manage in the future the sponsor expectations during the Spring 2020 semester?
- What was the biggest issue you had to deal with related to sponsors this past spring term?
- What was the biggest help in dealing with the above issues?

Prototypes and Final deliverables

- Which of the following deliverables for the capstone project change as a result of COVID-19? (final report, final presentation, self and peer evaluations, physical prototypes, capstone expo)
- How did the selected deliverables change for the projects a a result of COVID-19?
- Did you have a final capstone event for Spring 2020 semester?
- What format did you follow for the final capstone event? What worked well and what did not?

APPENDIX B: TABLE OF RESOURCES RECOMMENDED BY CAPSTONE PRACTITIONERS

Resource with Keywords	**Names of tools that have been recommended first-hand by Capstone Practitioners**
Digital workspace for visual collaboration, brainstorming, and decision making; electronic note boards	Etherpad, GroupMap, Ideaflip, Jamboard, Lucid Chart, Miro, Mural, Padlet, Stormboard, Stormz
Team formation; group creation; team maker	CATME, GRUEPR, IEEE, Indigo Project, Team Tools, Teammate
Team evaluation; peer assessment; responsibility and performance appraisal	CATME, FeedbackFruits, ITP Metrics, Peerceptiv, Tandem at U. of Michigan, TEAMATES
Project management; structured project planning;	Basecamp, JIRA, Microsoft Project, Monday, NutCache, Slack, Smartsheet, Trello, WorkZone
Online prototyping support	Adobe Experience Design, Balsamiq, AutoDesk, Fusion 360, InVision, Onshape, TinkerCAD, Proto.io