2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #33669

Industry-University Capstone Design: How Did Students Adapt to the COVID-19 Pandemic?

Ms. Shruti Misra, Unviersity of Washington

Shruti Misra is a graduate student in Electrical and Computer Engineering at the University of Washington, Seattle. Her research interest is broadly focused on studying innovation in university-industry partnerships. She is interested in the various ways that universities and industry come together and participate in driving technological innovation at the regional and global level.

Dr. Denise Wilson, University of Washington

Denise Wilson is a professor of electrical engineering at the University of Washington, Seattle. Her research interests in engineering education focus on the role of self-efficacy, belonging, and other non-cognitive aspects of the student experience on engagement, success, and persistence and on effective methods for teaching global issues such as those pertaining to sustainability.

Industry-University Capstone Design: How did students adapt to the COVID-19 pandemic?

Abstract

A 2015 survey of 256 institutions from the US revealed that 70% of their capstone programs were funded by industry and government sponsors. This indicates the pervasiveness of capstone programs that partner with external sponsors to provide a “real-world” design experience to students. In this vein, the industry-sponsored Engineering Innovation and Entrepreneurship (ENGINE) capstone program was established at the Department of Electrical and Computer Engineering at a large research university in the US. ENGINE is designed to provide a holistic and professional engineering experience to students in an educational setting, where student teams work on a six-month long project under the guidance of an industry and a faculty mentor. The program is overseen by a course instructor and teaching assistants who manage the course structure and expectations.

This study compares student experiences in ENGINE during remote learning necessitated by the COVID-19 pandemic to those in traditional, in-person learning. ENGINE students were surveyed in Spring 2018 and Spring 2020 to understand which components of the ENGINE program mattered most to student learning and how. Close-ended survey responses were analyzed using statistical methods and short answer questions were analyzed using qualitative methods in a sequential, mixed methods approach. Exploratory factor analysis of the Likert-scale items revealed that measures of instructional support and “real-world” experience contributed to student learning. No statistically significant differences in these measures between remote and traditional learning environments emerged. To address this lack of difference, a qualitative analysis was conducted to understand how the student capstone design experience changed during the pandemic.

The qualitative analysis revealed that the lack of significant difference may be due to the fact that students rapidly adapted to the remote learning disruption. The results provide an insight into the various ways in which students acclimated to the crisis circumstances. These adaptations manifested in the form of product and process adaptations, in which students swiftly adjusted their final product or design process to respond to the evolving crisis. Students used various strategies such as changing team roles and ways of communication, using different tools and technology, and creative technical solutions to drive product and process adaptations. However, these adaptations may have come at the cost of students' mental health. By shedding light on student experience of the capstone during the pandemic, this study acknowledges the resilience students have displayed during a crisis, while recognizing that the cost of such resilience must not be neglected.

Introduction

In March 2020, the World Health Organization declared the COVID-19 virus a global pandemic [1], which necessitated preventative measures such as social distancing and forced many higher education institutions to close campuses, abandon traditional practices of in-person classes and rapidly switch to remote learning environments. Consequently, students had to adapt to their new and unprecedented learning environments in very limited time. During normal circumstances, remote instruction can be beneficial as it provides students and instructors with the flexibility to teach and learn from anywhere. However, the nature of the transition during the COVID-19 pandemic cannot be compared to traditional models of online learning. These models involve prior planning and preparation to deliver course content tailored to the online setting. The development time for a fully online university course can range between six to nine months prior to its delivery. Moreover, it can take two or three iterations of an online course for faculty to feel comfortable with teaching it. During the COVID-19 pandemic, instructors did not have the time to carefully design and transition face-to-face courses to an online environment. Remote learning during the pandemic was a temporary response to a quickly evolving crisis. It was not intended to be a robust online educational experience, but rather a way to provide emergency access to instruction in a rapid and consistent manner. Therefore, remote instruction during the pandemic has been termed as emergency remote teaching (ERT) to distinguish it from traditional online teaching and learning [2]. Under ERT, organizational support that is usually available to assist faculty with implementing online learning was overextended due to the greater number of faculty who needed it during the pandemic. The lack of time and support that characterizes ERT may have resulted in a lower quality educational experience for students despite urgent and intensive preparations made by instructors. At the present time, insufficient evidence is available to assess to what degree higher education and learning may have been compromised by the shift to ERT.

While the broader setting of this paper is contextualized by emergency remote teaching, for the sake of simplicity, ERT will hereafter be referred to as remote learning. Much of the conversation around education during the pandemic has focused on the challenges faced by students and teachers as a consequence of the rapid switch to remote learning. Some of these challenges include declining mental health of students and faculty, unsafe and unsupportive student home environments, lack of technical skills and resources, lack of teaching experience in a remote environment, compromised assessment, and reduced classroom engagement [3,4,5,6]. However, not much attention has been placed on how students have adapted and demonstrated resilience during the pandemic. While instructors were focused on pivoting their courses to a remote setting, students also had to make adjustments in order to adapt to the sudden changes in their education. A study of second-year undergraduate students examined the role of self-discipline as a method of student adaptation during the pandemic. Students used actions such as time management, boundary setting, “being present” and removing distractions as ways to acclimate to the new learning environment [7]. Another study set in China and South Korea, found that students engaged in increased and proactive communication with peers and instructors to compensate for the lack of in-person engagement. The study concluded that students have been more resilient in the face of crisis, than previously assumed [8].

Given the challenges of remote learning and evidence of student adaptations, it is important to acknowledge the student experience and resilience during a time of crisis, especially of graduating seniors. The economic downturn and job losses caused by the pandemic resulted in a 9.2% increase in unemployment as a percentage of the labor force, in the U.S between February 2020 and May 2020 [9]. Therefore, college seniors were preparing to enter a workforce which was facing a severe shortage of jobs. Seniors were not only coping with the transition to remote learning but were also coming to terms with the uncertainty in future employment prospects.

To understand how the pandemic affected college seniors, this study focuses on the industry sponsored design capstone at a large public institution in order to understand how students perceived, adapted to, and mitigated the impact of the pandemic. The senior design capstone is a culminating project-based experience, which allows students to apply their engineering skills to real-world problems. In industry sponsored capstones, students learn how to work in teams to scope, ideate, design, and test a working solution to a problem posed by industry sponsors. Additionally, students also learn how to communicate with their industry mentors, faculty mentors, and team members to ensure that the project is a success.

Background

The Accreditation Board for Engineering and Technology, Inc (ABET) requires that undergraduate engineering program student outcomes emphasize applying “engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors” [10]. Capstone courses are often designed to address this requirement by providing a significant and often open-ended design experience in the final year of undergraduate education. Industry sponsored capstone programs are one way to deliver this design experience by providing students with the opportunity to work with industry mentors on designing solutions for relevant, real-world problems. According to a 2015 survey of engineering programs in 451 institutions, 79% of the design capstone programs were funded by industry, government or other external sponsors [11], indicating the pervasiveness of such a capstone context. Although prevalent, these capstone programs vary greatly in their implementation across institutions. The programs may vary in length (one or two semesters) [11], assessment [12], number of students enrolled, number of students per team [11], and topics covered [13].

As part of industry sponsored capstones, students learn how to work with various industry and faculty stakeholders and undergo a complete engineering design experience from the ideation stage to the evaluation stage. A study that surveyed their institution’s Engineering Management industry sponsored design capstone found that students benefit from the ambiguous and open-ended nature of “real-world” problems that may not have a single correct solution. Capstones provide a space for students to develop a solution concept based on sponsor requirements, make design choices and tradeoffs, and evaluate their design in a realistic setting [14]. In the process of their design work, students learn how to communicate effectively with their peers and mentors through multiple modes such as written reports, presentations, in-person work sessions, team meetings and other informal conversations. Learning how to communicate advances successful collaboration and teamwork, which is another beneficial skill students gain during their capstone experience. Student teams also develop skills in project management, which includes project planning, scheduling and budgeting.

The shift to remote learning due to the COVID-19 pandemic had dramatic impacts on undergraduate engineering education. Industry sponsored engineering capstone programs were no different and suffered many of the challenges associated with the rapid switch to remote learning. Campuses were closed and laboratories became inaccessible, thereby imposing severe restrictions on available resources to engineering students. The loss of communal workspaces that resulted from lockdowns and closures also hindered team collaboration and communication and disrupted project schedules. While the pandemic created many barriers to the capstone design experience, it also provided a substantial real-world constraint for students to assess and address. In this respect, the pandemic was an unanticipated learning opportunity for students to learn how to improvise, innovate, and adapt over the course of their design experience.

A limited number of studies have examined how the capstone design experience changed during the pandemic. Jamieson reflected on the challenges during the pandemic and strategies used to preserve the quality of the students' learning experience in a chemical engineering capstone, a senior design course and a transdisciplinary freshman course. One of the key concerns that students and instructors had was about the impact of remote learning on student outcomes, especially in the context of team-based work, as all three courses involved teamwork. To address this concern, instructors had to ensure that students had a way to engage with teaching assistants (TAs), industry mentors, and their design team in order to complete their project. Moreover, some students and TAs were in different time zones as a result of relocating due to campus closures, which created further communication barriers. Structured online meetings were conducted to facilitate interaction among peers and between teams and mentors. Having a structured and consistent online meeting format ensured that a healthy amount of communication was occurring among various project stakeholders. Of particular relevance to this study, seniors displayed a strong commitment to completing their projects. The support of an industry mentor and other peers seemed to foster resilience in this setting [15].

Teamwork and communication seemed to be the hardest hit aspects of capstone projects during the pandemic. Wildman et. al. studied the perceived impacts of the remote transition on team processes and performance in long-term student projects (sixteen weeks or longer). The study surveyed students working in teams within upper-level undergraduate courses including engineering design capstone projects and psychological research projects. Three main themes emerged from study: 1) challenges to student teams 2) changes to team processes and communication and 3) consequences that teams faced due to the online shift. Challenges that teams faced included the impact of outside influences such as increased distractions in the home environment that hampered the team's ability to coordinate, communicate, and achieve shared goals. Differences in time zones also exacerbated some teams' ability to effectively communicate and collaborate. Teams also faced performance issues from some team members such as perceived forgetfulness, increased procrastination, and exacerbated issues of social loafing. While the challenges seem to have instigated changes to team processes with the use of new modes of communication such as Slack, Zoom and WhatsApp, the quality and quantity of communication varied between teams with some successful and some not. In a few cases, communication between team members actually improved as some students perceived online meetings to be more efficient than face-to-face meetings. And finally, teams had to deal with how tasks were to be completed, shifting both tasks and roles to accommodate the lack of a physical workspace or laboratory in which to collaborate. The consequences of these challenges and changes due to remote learning were in most cases, negative. Teams lost momentum of work, lost morale, and faced increased ambiguity surrounding their projects. For a minority of teams, however, the pandemic had little to no impact. This challenges the unspoken assumption that the impacts of COVID-19 on performance and well-being are overwhelmingly negative [16].

The pandemic also impacted the project management aspect of engineering design capstones by restricting access to resources such as laboratories and makerspaces. In a senior biomedical engineering capstone design course at Marquette University, Goldberg examined the pandemic-induced loss of the main makerspace and the resulting actions taken to facilitate student learning. Teams with members who remained on campus or lived within driving distance were allowed to retrieve components from the makerspace while following social distancing and other public health guidelines. Simulation and modeling software were made available for use on students' laptops and computers. Students could submit CAD drawings to the makerspace for 3D printing prototype parts, which were then shipped to them. Students were encouraged to improvise and use alternate resources that were available locally as long as they did not jeopardize their health. If the project budget allowed, student teams were encouraged to purchase duplicates of needed supplies and tools. Based on the availability of campus and local resources, faculty advisors determined whether teams would be able to complete their projects. Course expectations were adjusted and project scope was reduced for teams who could not access the necessary resources for project completion. Partially functioning or non-functioning prototypes were accepted if functional prototypes could not be completed. In combination, rescoping projects and identifying multiple alternative resources for students resulted in all teams completing their projects within the new project scope. Ten out of the 21 teams were able to complete their prototypes without additional resources; nine teams submitted non-functional prototypes; and two teams submitted non-functional scale models [17].

These studies provide rich qualitative data regarding how capstone design experiences evolved in and survived the COVID-19 pandemic. Rather than focus on instructional changes, this study complements existing studies by taking a quantitative and qualitative look at how and when capstone design students adapted to the abrupt transition from traditional to remote learning.

Methods

This study was conducted at a large public research university in an electrical and computer engineering capstone design course known as the Engineering Innovation and Entrepreneurship (ENGINE), which spanned two quarters (i.e., 20 weeks). It adopted an explanatory sequential mixed methods approach [18] to first identify, using the quantitative analysis of Likert-scale survey data, the ways in which the capstone experience during the 2020 COVID-19 pandemic differed from the traditional capstone experience offered in 2018. Subsequent qualitative analysis used student reports and other assignments to explore and explain these differences (or similarities). Multiple research questions guided this study:

RQ1: What are the factors that contributed to student perceptions of learning in the ENGINE capstone program during COVID-19?
This question was investigated using an exploratory factor analysis of 13 Likert-scale questions posed to students in a survey administered during the last month of their capstone design experience. The resulting factors supported a comparison between the traditional and remote learning capstone cohorts.

RQ2: Was there a difference in student perceptions of learning during the COVID and non-COVID iteration of the capstone?

Standard statistical analysis techniques were used to compare the factors identified in RQ1 between traditional and remote capstone cohorts. Resulting differences (or lack thereof) guided the qualitative analysis in RQ3.

RQ3: How did the student capstone design experience change during the COVID-19 pandemic? Qualitative analysis of student assignments and reports relevant to their capstone design experience was used to dive deeper into understanding why, how, and how much students exhibited resilience during the COVID-19 crisis and adapted to restrictions in resources and other changes that evolved from lockdowns and other public safety measures.

Setting

The setting for the study is the industry sponsored capstone design sequence at a large research university in the U.S. The ENGINE capstone is a two-quarter program spanning winter and spring quarters for a total of 20 weeks. The ENGINE program typically hosts about 115 students, approximately 100 of which are electrical and computer engineering majors. Students have an opportunity to select from about 35 projects. Approximately 90% of the projects are sponsored by industry, while the remaining may be sponsored by faculty and/or government organizations.

In the first quarter of ENGINE, student teams develop and scope a project proposal with their industry mentors. The project proposal outlines the purpose of the project, a timeline of the goals and milestones, and budget and resource projections. Once a scope and plan are established in consultation with both industry and faculty mentors, teams move forward to project realization, which continues until the end of the program. The students are usually provided with access to a laboratory space with necessary equipment to aid the development of their projects. Additionally, industry sponsors may also provide teams with access to their facilities and resources for project work. The teams engage in biweekly meetings with teaching assistants (TAs) to report on their progress and share any concerns they may have. Students participate in a preliminary project review presentation at the end of the Winter quarter. In the Spring quarter, these teams prepare a final report detailing their design process and also showcase their project in a poster fair at the end of the Spring quarter.

In the traditional learning setting, TA meetings, most industry meetings, the project review, and the poster fair all occur in person. However, the COVID-19 pandemic caused the Spring quarter half of the capstone design experience to shift to remote learning. By this time, students had developed their project scope and proposal and had conducted some initial design work. They had no opportunity to anticipate nor plan for the sudden changes effectuated by the pandemic. All meetings with TAs and mentors were moved on-line. Additionally, the project presentations and poster fair were conducted virtually and campus resources and spaces, including the capstone lab facility, were closed.

Nature of Projects

The capstone program featured a diverse range of projects across multiple topic areas. The projects can be categorized broadly by the level to which they focus on hardware or software. Based on this bird's eye view, the capstone projects were grouped into three types for this study:

purely software projects, purely hardware projects, and projects that contained both hardware and software components (hardware/software). Purely software projects were almost entirely focused on software programming and for the most part, required students to work on their own personal computers to run programs and code. In contrast, purely hardware projects involved physical hardware that students had to fabricate, test, or otherwise incorporate into their designs. These projects involved minimal to no software programming. The third category of projects consisted of both hardware and software components. Table 1 provides a breakdown of the number of projects by category in the 2018 and 2020 iterations of the capstone.

Table 1: Project Categories

Project Type	*Count*	
Year	*2018*	*2020*
Purely software projects	15 (55.6%)	11 (31.4%)
Purely hardware projects	1 (3.7%)	2 (5.7%)
Hardware and Software projects	11 (40.7%)	22 (62.9%)
Total	27	35

Participants and Procedures

The participants for this study were two cohorts of students who enrolled in the ENGINE capstone during 2018 and 2020 offerings of the capstone. An online survey was conducted mid-way through the Spring 2018 and Spring 2020 quarters and enabled students to self-report which aspects of the program aided or inhibited student learning. In 2018, 96 students were surveyed, and 25 students responded (26% response rate). In 2020, 115 students were surveyed, and 79 responses were received (69% response rate). All participation was voluntary, and students were informed that their survey responses would remain confidential. No identifying information was collected, including student name, demographics, and name of their project or industry sponsor. Furthermore, no attempt to oversample women or minorities was made in collecting the sample data. All results are cross-sectional.

Instruments

Multiple sources of data were used for this study. Ordinal (Likert-scale) data was collected from student surveys regarding perceptions of how different aspects of the course contributed to student learning (Table 2). For the qualitative analysis, sources of data included two major documents submitted by student design teams during Spring 2020: (1) a COVID mitigation plan prepared and submitted at the beginning of spring quarter and (2) a final project report which included details of how their project was altered due to the pandemic. The two sources of data were used to investigate RQ3.

Table 2: Capstone Student Survey Questions

<table>
<tr><th>Type of Question</th><th>Scale Description</th><th colspan="2">Item</th></tr>
<tr><td rowspan="15">Likert Scale</td><td rowspan="15">1. Strongly disagree
2. Somewhat disagree
3. Somewhat agree
4. Strongly agree</td><td colspan="2">How much has each of the following course components contributed to your learning so far (last quarter and this quarter)?</td></tr>
<tr><td>Full Description</td><td>Short Description</td></tr>
<tr><td>doing project work</td><td>Project</td></tr>
<tr><td>working with teammates</td><td>Teamwork</td></tr>
<tr><td>having a real industry project</td><td>Experiential</td></tr>
<tr><td>teammate peer evaluations</td><td>Evaluations</td></tr>
<tr><td>preparing and giving presentations</td><td>Presentations</td></tr>
<tr><td>receiving/providing feedback on presentations</td><td>Feedback</td></tr>
<tr><td>guidance from faculty mentor(s)</td><td>Faculty</td></tr>
<tr><td>guidance from capstone instructor</td><td>Instructor</td></tr>
<tr><td>guidance from industry mentor(s)</td><td>Industry</td></tr>
<tr><td>guidance from capstone TAs</td><td>TA</td></tr>
<tr><td>participating in TA-led mixers</td><td>Mixers</td></tr>
<tr><td>This capstone experience has helped me learn what I had hoped to learn at the start of winter quarter</td><td>Expectation</td></tr>
<tr><td>This capstone experience has expanded my appreciation of the range of skills/knowledge important in engineering.</td><td>Appreciation</td></tr>
<tr><td>Likert Scale</td><td>1. Less than 7 hours
2. 7-8 hours
3. 9-10 hours
4. 11- 12 hours
5. 13- 14 hours
6. 15-16 hours
7. 17-18 hours
8. 19-20 hours
9. More than 20 hours</td><td colspan="2">On average, about how many hours per week are you spending on capstone this quarter</td></tr>
</table>

Data Analysis

To address RQ1, an exploratory factor analysis was conducted. The ordinal (Likert-scale) data was analyzed using R (version 4.0.2) and R studio (version 1.3). Items were first assessed for suitability to a factor analysis. A correlation matrix was obtained, and off-diagonal values greater than 0.9 were removed to prevent redundancies. Next, Bartlett's test of sphericity and Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy were conducted. Bartlett's test checks whether the correlation matrix is an identity matrix. A small p-value for this test ($p < .001$) indicates that the variables are sufficiently correlated and suitable for factor analysis. The KMO measure signifies the proportion of an item's variance caused by underlying factors. Thus, high KMO values are usually desired. Items with KMO values less than 0.5 were removed [19].

Next, a principal component analysis (PCA) was performed on suitable items. The number of factors selected for PCA was based on the number of eigenvalues greater than 1 and the percent variance explained by the factors, with 60% or more being desirable [20]. Communalities were computed to identify items whose variance could not be justified by the factors. Thus, items with communality less than 0.4 were removed [19]. PCA was repeated until all communalities were greater than 0.4. After fixing the number of factors, PCA was repeated with an oblique ("promax") rotation, as items are assumed to be correlated and not orthogonal. Items that significantly loaded (loading > 0.6) onto one factor were retained [21]. Items that failed to load on any factor or had significant cross loadings were removed. The process was repeated until all items were distinctly grouped into factors without significant cross-loadings. The internal reliability of the factors was measured using Cronbach's alpha levels. Factors were identified as suitable for further analysis if Cronbach's alpha level was greater than 0.6 [20]. Eliminated items were examined to understand why they did not align with other survey items.

To address RQ2, descriptive statistics were first calculated for different scales that emerged from the exploratory factor analysis of the survey data, as were skewness and kurtosis to verify suitability for statistical analysis. Independent sample t-tests were then used to compare factors that were available for both the 2020 (remote learning) and 2018 (traditional learning) offerings.

RQ3 was evaluated by conducting a qualitative document analysis [22]. Each student team had a unique design experience situated in a context constructed by their project, industry mentors, faculty mentors, and the students themselves. A qualitative line of inquiry was well-suited to address this question as it offered tools to identify the common threads that wove together the varied design experiences of students during the pandemic. Therefore, two sets of documents for all 35 student teams were analyzed: final project reports and the mitigation plan assignment. The reports contained technical and non-technical aspects of the projects. The technical aspect of the reports included the design process, testing procedures, and results of the project. The non-technical aspect of the report consisted of team roles, socio-ethical implications of the project, and an explicit documentation of how the project was affected by COVID-19. The teams were also asked to submit a COVID-19 mitigation plan assignment in the beginning of Spring quarter, which detailed how the project and team structure would change during the quarter and whether the teams needed help accessing resources as they transitioned to a remote setting.

Project report and mitigation plan data were analyzed for emergent themes. The first round of coding for both sources of data was done individually and in an inductive manner to discover themes and patterns that were common among student experiences of the capstone during COVID-19. The next round of coding was based on the constant comparative approach, where themes emerging from the first round were compared and contrasted across student teams to create categories, establish and refine boundaries to those categories, and summarize the content of each category [23]. The categories were then compared across the different sources of data to leverage the discriminative power of the categories to identify patterns in the data that provide a more complete insight into the students' experience as they navigated the capstone program.

Results and Discussion

Survey data were analyzed to identify factors associated with student learning (RQ1). Factors were then analyzed using standard statistical analysis techniques to understand similarities and differences in student learning between traditional and remote learning (RQ2). Once these differences were identified, assignment and report data collected from 2020 ENGINE students were analyzed to understand how both similarities and differences between remote and traditional settings evolved during remote learning (RQ3).

RQ1: What are the factors that contributed to student perceptions of learning in the ENGINE capstone program during COVID-19?

Thirteen survey items were analyzed in the exploratory factor analysis. A correlation matrix of these items revealed that none of the items had off-diagonal values greater than 0.9. Therefore, at this stage, all the items were retained for further analysis. Subsequent tests of sphericity and measures of sampling adequacy indicated that all of the items had small p value ($p < 0.001$) and KMO values greater than 0.5. Thus, all items were retained for further analysis. Subsequent PCA analyses indicated that one item had communality less than 0.4. This item was removed from the analysis. Items with response rates less than 70% of survey participants were also removed due to low (and likely biased) sample size [24]. These preliminary analyses produced 11 items suitable for factor analysis. The two items eliminated from analysis at this stage are detailed in Table 3.

Table 3: Items eliminated from the quantitative analysis

Reason for removal	*Item*
Preliminary analysis: communality < 0.4	On average, about how many hours per week are you spending on capstone this quarter (including mentor meetings)?
Preliminary analysis: >30% no responses	How much has each of the following course components contributed to your learning so far? - participating in TA led mixers
Factor analysis: significant cross-loadings	How much has each of the following course components contributed to your learning so far - guidance from industry mentors)

Subsequent PCA analysis was conducted with a fixed number of factors – four (Table 4). One item was removed based on this analysis because of significant cross loadings (Table 3). Of the remaining items, three positively loaded onto the first factor which was subsequently labelled "Real-world Experience". This factor included three total items that were associated with the Project, Teamwork, and Experiential aspects of ENGINE. The second factor contained three significantly loaded items associated with student Presentations, Evaluations, and Feedback and in combination represented the type of assessment students underwent during the course. This factor was labelled “Assessment”. The third factor contained three items associated with Faculty, Instructor, and TA guidance. These items emphasized the instructional support students received and was labelled “Instructional Support”. The fourth factor consisted of two items used to measure students’ Expectation and Appreciation for the capstone. This factor was named “Task Value”, in the context of the capstone. *Task value* draws from expectancy-value theory, which assumes that student achievement and related choices depend on students’ confidence in their expectations to succeed in the course and their perception of the course’s value [25].

The four factors emerging from the factor analysis accounted for a total variance of 76 %, which is above the desired threshold of 60% [20]. Reliability (Cronbach's alpha) for all constructs was above 0.7, which is considered adequate for further study [20]. Therefore, these four factors were included in the analysis for the next research question (RQ2).

Table 4: Exploratory Factor Analysis of survey items

Items	*Construct*	*Factor Loadings*			
		Factor 1	*Factor 2*	*Factor 3*	*Factor 4*
Project	Real-world Experience	**0.816**	-0.187	0.168	0.122
Teamwork		**0.870**	0.079	-0.121	-0.210
Experiential		**0.847**	-0.070	0.029	0.164
Evaluations	Assessment	-0.324	**0.995**	0.092	0.085
Presentations		0.276	**0.754**	-0.092	-0.55
Feedback		0.251	**0.711**	-0.025	0.020
Faculty	Instructional Support	-0.063	-0.150	**0.960**	-0.036
Instructor		0.066	0.219	**0.716**	0.009
TA		0.158	0.203	**0.676**	-0.055
Expectation	Task Value	-0.097	0.081	-0.063	**0.901**
Appreciation		-0.037	-0.003	-0.005	**0.936**
% of Variance		22.1%	20.3%	17.8%	16.3%
Cronbach's Alpha		0.789	0.834	0.836	0.859
Eigenvalues		4.929	1.827	0.963	0.905

Two of the factors, namely *real-world experience* and *instructional support* were measured in both the remote and traditional iterations of the course. The other two factors were only measured in the remote offering of the capstone course due to a revised survey design.

Previous studies have shown that students were much more enthusiastic about their work if they were aware that it would be implemented in a realistic setting [14]. Therefore, the emergence of *real-world experience* as a factor in the ENGINE student experience is not surprising. Similarly, given the generally important role that faculty and teaching assistants (TAs) play in student learning as well as the importance of grades to undergraduates, the emergence of *instructional support* and *assessment* as factors in the capstone design experience is also justified. And finally, the fourth factor, *task value* serves as an indication of students' motivation to participate in the ENGINE capstone experience. *Task value* draws from expectancy-value theory and has been demonstrated to be a distinct contributor to academic engagement and effort [26, 27] as well as educational and career aspirations [28].

RQ2: Was there a difference in student perceptions of learning during the COVID and non-COVID iteration of the capstone?

Table 5 summarizes the descriptive statistics for factors from the 2018 and 2020 student surveys. All items were evaluated on a 4-point Likert scale. The survey in 2018 did not contain items corresponding to all factors, therefore only factors that were fully represented in both surveys were considered. These factors were *real-world experience* and *instructional support*.

To identify suitable statistical tests for subsequent analysis, skew and kurtosis were evaluated for both *real world experience* and *instructional support*. Skew and kurtosis values for both constructs lay between -2 and +2, indicating sufficient normality that independent samples t-tests could be used to test for statistically significant differences between the factors in the remote and traditional settings [29].

Table 5: Descriptive Statistics of Factors that emerged from EFA of the 2020 Survey

Factor	*Real-World Experience*		*Instructional Support*		*Assessment**		*Task Value**	
Year	*2018*	*2020*	*2018*	*2020*	*2018*	*2020*	*2018*	*2020*
Mean	3.43	3.38	2.39	2.7	-	2.7	-	3.09
Median	3.67	3.67	2.33	2.67	-	2.67	-	3
Standard Deviation	0.57	0.66	0.95	0.81	-	0.88	-	0.91
Skew	-0.8	-1.04	0.23	-0.17	-	-0.13	-	-0.88
Kurtosis	-0.33	0.33	-1.23	-0.48	-	-0.94	-	-0.16
p-value	0.739		0.110		-		-	

*Factors not computed in 2018

As shown in Table 5, the *real-world experience* and *instructional support* reported by students were not significantly different in traditional vs. remote learning. There are a number of possibilities why this may be the case. First, the low survey response rates in the traditional offering of the ENGINE capstone (26%) may have generated too small a sample or a biased sample. Or it is possible that instructors adapted the course expectations to meet the demands of the moment in the remote learning offering of the capstone. To some degree, this is true as instructors displayed flexibility with deadlines and the final deliverables. For example, students were graded based on their altered project plans as formulated in the mitigation plan assignment. Synchronous design review presentations were also cancelled. Instead, student teams were required to submit design demo videos to offer teams the flexibility to present their work asynchronously.

Another possibility for the lack of significant differences between traditional and remote learning is that students adapted rapidly to the remote learning disruption. A few studies have examined student resilience during the pandemic. Self-discipline and proactive communication have been found to be two ways in which students mitigated the switch to remote learning [7, 8]. These studies suggest that students may have been more resilient than previously thought. However, the quantitative data examined in this study does not provide any insight into how students might have adapted and displayed resilience to the changes enforced by the pandemic. Understanding how students may have adapted was the focus of RQ3.

RQ3: How did the student capstone design experience change during the COVID-19 pandemic?

To further examine student capstone experiences during COVID-19, a qualitative document analysis of student reports and assignments was conducted. The abrupt transition from traditional to remote learning in Spring of 2020 resulted in three basic types of adaptations in the ENGINE capstone experience for students. In the first category (*product adaptation*), the design experience of a subset of project groups was severely disrupted by the pandemic, causing student design teams to revisit project scope and rescope aspects of the project to suit the remote environment. These projects experienced changes to both final product and deliverables. A second category of projects (*process adaptations*) did not have to rescope project goals and deliverables, but their process was nevertheless affected by the pandemic. In the project realization phase, these groups were able to deliver their final product, but were unable to test or validate the final design. They adapted by working from a significantly reduced dataset or reducing expectations of their project validation phase. The final category (*no change*) involved no product or process adaptations at all.

Of the 35 projects in the 2020 offering, 71.4 % of all projects underwent some change either in their product or process, and 28.6% of the projects faced no changes. Product adaptations were experienced by 42.8% of all projects, including eight instances of reduced scope, four instances of software simulation replacing prototype construction, and three instances of no system integration. Of all the projects, 28.6% underwent process adaptations including nine instances where testing and evaluation of the final product did not occur and three cases where data collection for validating the final product did not take place (Table 6). This myriad of adaptations reinforces the notion that COVID-19 caused major disruptions to the traditional student experience of the capstone program despite the absence of significant differences in student perceptions associated with RQ2.

Table 6: Changes in Capstone Projects as a Result of Remote Learning

	Product Adaptations	*Process Adaptations*	*No Change*
Software	2	1	8
Hardware	1	1	0
Hardware and Software	12	8	2
Total number	15	10	10
Percentage	42.8%	28.6%	28.6%

What changed for students? (Figure 1): Product and process adaptations were driven by a range of constraints introduced by the COVID-19 pandemic and are discussed next.

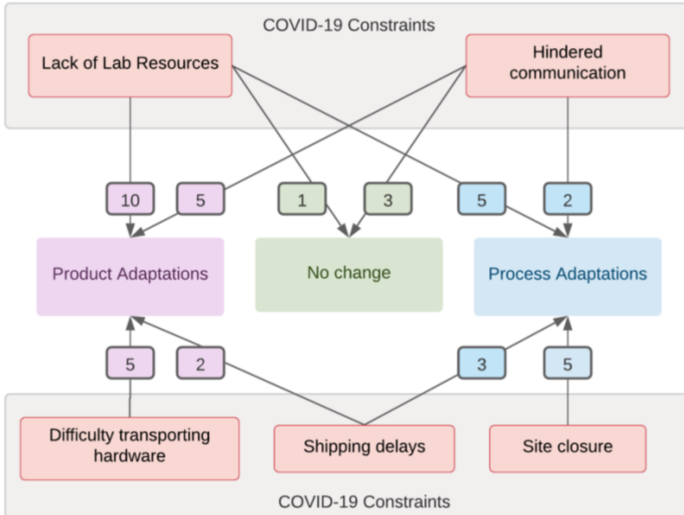

Figure 1: A mapping of COVID-19 constraints and project changes. Numbers indicate the number of projects in each category

Product Adaptations: Approximately half of the capstone projects (42.8%) had to adapt by either reducing their project scope, switching the nature of the product from a physical prototype to software simulation, or forgoing integration of different subsystems into a complete system. One student captured the magnitude of the changes in product in one simple sentence:

> Many previously required deliverables have now become stretch goals for the project.

As shown in Figure 1, the most prominent reason underlying product adaptations was the inability of teams to access on-campus or company laboratories which contained equipment essential to project development, especially for hardware leaning projects (43.5%). For many teams, this meant that they could not access equipment such as 3D printers, high-performance computing machines, oscilloscopes etc., which are expensive to set up at home. This was also the main reason why some hardware-oriented teams decided to pivot their final product to a software simulation instead of a physical hardware prototype. Teams adapted to the lack of access to these resources by recalibrating and reducing expectations and requirements for their project deliverables. Hindered communication and collaboration was the second most common reason for product adaptations (26.1%). The remote learning environment made it difficult for teams to design, debug, and troubleshoot their projects together. One student summed the challenge up as follows:

> Due to the COVID-19 virus, integrating and designing hardware became very difficult. Not being able to meet in person, made the development of hardware very challenging.

Teams also had a challenging time communicating with their mentors or other project stakeholders as a result of changes in the stakeholders' operations and priorities due to the pandemic. Therefore, teams changed their project expectations and deliverables to overcome the lack of information from external sources. Difficulty in transporting hardware (21.7%) and shipping delays (8.7%) also motivated product adaptations. Some teams had to share a single device for testing and such sharing was hampered and delayed by social distancing and remote learning. Other teams relied on lab space for teams to store and share their hardware prototypes. Still other students experienced disruptions and delays in the supply chain, particularly for parts that were made in China. For example:

> Due to the outbreak of COVID-19 we experienced significantly increased lead times on parts and were forced to purchase more expensive parts from different retailers when initial shipments were delayed. Delays had the greatest impact on our end-effector design.

Process Adaptations: Around a third (28.6%) of all projects had to adapt their design process in light of the constraints imposed on them by the pandemic. Two of the most common constraints that underlie process adaptations were lack of access to lab resources (33.3%) as previously discussed and closure of data collection and testing sites (33.3%) due to social distancing measures. The following sentence succinctly describes process adaptations due to site closure:

> With the new stay-at-home order in place, we will not be able to do any on-site testing or final proving. Our deliverables will remain the same; but our methods of proving our system works will be changing.

In some cases, students required access to the sponsoring company's facilities to test their device on company equipment. However, many of these sites were inaccessible during the pandemic. In addition to testing, a few teams also could not collect the relevant data required for their project due to site closure and lack of lab resources. These teams resorted to using a heavily limited dataset that could be collected at home to test their final product:

> Since COVID-19 pandemic limited how many people we could test the model on, the model was only trained to recognize the members of the team's faces. We recognize that our testing would have been more robust if we could have tested the system on more than four people. In the future we would suggest testing this system on a larger scale.

Shipping delays caused by supply chain problems due to the pandemic was also a common constraint driving process adaptations (20.1%). For some projects, the increase in lead times of components resulted in delayed design timelines, leaving no time for testing. Like product adaptations, hindered communication due to the remote nature of the course also motivated process adaptations (13.3%). Students raised concerns regarding reduced work efficiency and team coordination along with the difficulty of expressing ideas remotely as challenges that hindered their process.

No Change:

> Since the project was purely software-based and there was no requirement of any Hardware/Lab and thus the COVID-19 situation did not affect the progress of the project.

Around a third of the projects in the capstone did not see any change in their process or final product. Unsurprisingly, around 75% of those projects were software projects. This is largely because most of the COVID-19 related constraints such as lack of lab space and resources, difficulty in transporting hardware, site closure, and shipping delays did not impact these teams due to the software nature of their projects. These teams had access to the resources they needed, mainly because the resources could be shared remotely. Only in the case of one team was there a constraint on resources such as access to Graphics Processing Unit (GPU) computers which were inaccessible due to lab closure. The only change many of these teams faced was a switch from in-person to remote interaction and time zone changes of some team members and industry mentors, which some students expressed as being challenging. Overall, however, the switch to remote interaction was mitigated by the fact that collaboration on software projects is amenable to a remote setting.

How did students adapt to these changes (Figure 2): Of the many ways that students adapted to the constraints wrought by the pandemic, changing team roles and structure (26.3%) and using different tools and technology (26.3%) were the most common.

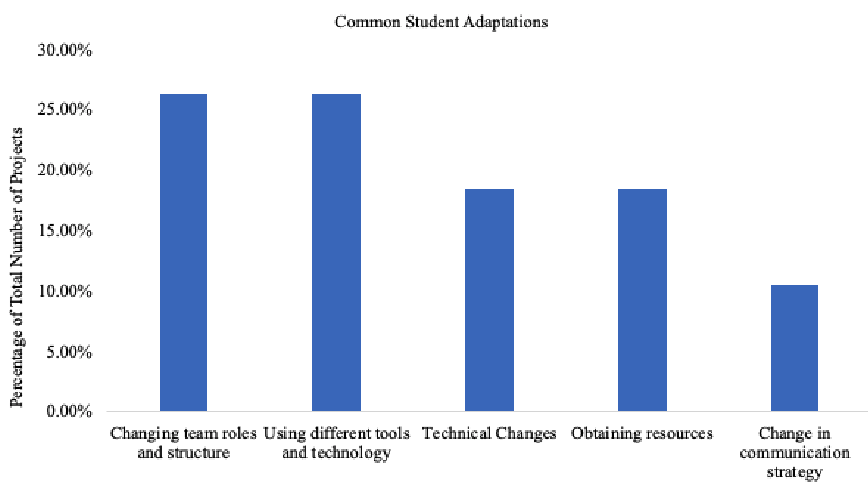

Figure 2: Student adaptations to project changes due to COVID-19

For instance, some teams moved to more independent rather than collaborative roles:

> Since we could not meet in person, we met with our industry mentor and instead decided that we would each be allocated different tasks that could run independently of each other.

Independent roles were very common in hardware leaning projects, but students employed other strategies in software projects. For example, one team employed a cyclic approach to mitigate not being able to develop code together:

> Since we were unable to meet in person, the outbreak did make it difficult to partner. As a result, it was difficult to work on the same tasks at the same time, so we needed to compromise and adapt. For instance, for the web demo, it was mostly one person pushing to GitHub then the other person continued where the first person left off, and this cycle kept repeating.

Students also reported using a myriad of tools and technology to successfully complete their capstone projects. In addition to using tools such as Zoom and Microsoft Teams for communication, some teams used the screen sharing function on these platforms for peer coding instead of physically coding together. Other teams started using project management tools such Trello or Jira to maintain team member accountability, track resources, and ensure that deadlines were being met. Several teams also started using messaging platforms such as Slack to maintain active communication among team members and with industry sponsors.

In another way of adapting to COVID-19 constraints, some teams improvised technical changes to their final product and testing strategies (18.4%). Students got creative about how to test and verify their devices. In the example below, a team described how they tested their prototype after being unable to conduct on-site testing and gather data due to social distancing:

> For testing our turn angle device, we gathered data against a flat wall. We manually turned the device and physically measured the turn angle using tape measures to check how accurate our data was. To prove our calculation of the trailer length and wheelbase, we moved to a simulation in the Unity game engine.

Other examples of creative approaches to technical changes included porting a system to a cheaper, reduced scale robot that could be worked on at home and replacing hardware modifications with equivalent software changes. Still other student teams dealt with stay-at-home constraints by partially or fully strategizing to coordinate resources (18.4%). A few teams coordinated socially distanced hand-off and transportation of hardware, either by driving it around, shipping it, or using on-campus lockers. Some teams had the foresight to obtain all needed equipment from labs before labs closed down.

Finally, some students changed the way they communicated to get around the collaboration and communication restrictions they faced while transitioning from an in-person to a remote setting (10.5%). The most frequently used strategy was to increase meeting frequency to stay engaged and ensure that everyone remained on track. One student summarized this shift as follows:

> The pandemic forced the team to be more resourceful and communicate in new ways to achieve and complete all milestones

Students adapted to the pandemic by changing their product or process and responding to constraints in swift and innovative ways. This may explain why student perceptions of learning were not different across the remote and traditional setting. The quantitative survey did not have items that captured *how* students adapted to the pandemic. While the *real-world experience* factor, consisting of items such as “doing project-work”, “having a real industry project” and “working with teammates” provided a general notion of what contributed to learning, it did not reveal the dynamic way in which “real-world experience” changed between 2018 and 2020. A similar argument can be made for “instructional support”. While “guidance from instructor, TAs and faculty mentor” offers a broad idea of what contributed to student perceptions of learning, it does not reveal how the instructors and TAs adapted course expectations during the pandemic. Therefore, the lack of change in perceptions between the remote and traditional settings can be explained by the mitigating efforts and adaptations of students, which may have resulted in an equivalent if not equal capstone experience during the pandemic

One of the key goals of the industry sponsored engineering design capstone is to provide students with the opportunity to apply their engineering knowledge to design solutions to relevant, real-world problems. This includes accounting for various societal, economic, and environmental constraints. The COVID-19 pandemic emerged as a form of unanticipated socio-economic constraint that profoundly upended life, work, and education across the globe. While it disrupted the design experience of many student teams, it also provided them with the opportunity to learn how to make engineering and design decisions with agility in an uncertain environment. Student teams used various strategies and decisions to mitigate the ambiguity and disturbances caused by the quickly evolving pandemic situation.

However, this learning opportunity may have come at the cost of students’ mental health and wellbeing. Multiple students clearly spoke to the pandemic as being a very challenging time in their lives due to reasons external to their education or due to difficulties with remote learning. Some reported that their team was falling apart as team members were difficult to reach and communicate with. These students voiced serious doubts about being able to complete their projects. Students also expressed that they felt pressured to continue with the capstone despite their declining mental health because their graduation and job offers were contingent on completing the course. A few students stated that they should not be expected to work in full capacity in the middle of a global pandemic. These struggles are in alignment with existing research on the effects of the pandemic on student mental health and teamwork [4,5,16].

Ultimately, the severity of mental health impacts that some students experienced during the 2020 capstone begs the question: were student adaptations at the cost of their mental health too high a price to pay? This is a question that has not yet been considered as education research on the impact of the COVID-19 pandemic continues to grow and expand.

Limitations

The present study offers a unique contribution to the engineering capstone literature by focusing on student perspectives and adaptations during a pandemic. The study draws on a capstone design experience at a single institution and the generalizability to other academic settings may be limited. The quantitative aspect of the study provided a set of factors that can measure student perceptions of learning in a single capstone course. However, the survey results might be prone to self-selection bias, especially given the low response rate from the traditional capstone offering. Students were not incentivized to participate in the survey. Since it was a course evaluation survey, it is possible that those who participated might have been motivated to respond to communicate extreme negative or extreme positive experiences. Therefore, the survey may not have reflected responses from students in the middle of the spectrum, who had an average experience.

One of the main limitations of the qualitative analysis in this study is that the analysis and interpretation are based on the subjectivity of the researcher, who is also the main instrument of the research [22]. But the multiplicity of data sources served as a form of triangulation to render credibility to the findings of the study. Another limitation is the positionality of one of the authors with respect to the study. The author was a teaching assistant for the capstone program during both the settings being studied. Her interpretation of students' design experience is prone to some "biases, dispositions and assumptions regarding the research" [22] that may have influenced the interpretation of the themes, as she was embedded in the capstone process.

Despite these limitations, the results of this study offer rich insight into how students adapt to extreme or crisis circumstances that can be used to inform future capstone and engineering design instruction when projects take unanticipated turns.

Implications

This study has suggested that college seniors are very capable of adapting to sudden changes in their education and design trajectories and that their resilience has been underestimated. Increased resilience and capacity for adaptation opens up a range of possibilities for undergraduate education in terms of offering students design opportunities that may be open-ended, dynamic, and subject to multiple changes over the course of the engineering design cycle. For engineering design and capstone instructors, this can mean expanding the range of projects presented to students and deepening the real-world experience that they receive while still in college.

While students showed creative and significant resilience in the face of COVID-19 in adjusting, rescoping, and completing their capstone design requirements, many also openly admitted to the toll that the experience took on their mental health. In some instances, students acknowledged the severity of the mental toll associated with the pandemic. Issues external to school and difficulties with group work due to unresponsive team members caused mental stress that for some, was extreme and threatening to their well-being. Several students also expressed that they should not be expected to complete a capstone in the midst of a pandemic. Thus, while the resilience of engineering students was documented in this study and speaks to the ability of students in general to adapt and be resilient when provided appropriate instructional support and adjustment in summative assessments, there is a price paid for that resilience that cannot be neglected.

Conclusions

Much of the discussion around shifting from traditional to remote learning as a result of the COVID-19 pandemic has focused on the reduced quality of education that is likely to result from being outside of the classroom and online. While the jury is still out on the degree to which this shift has truly impacted the quality of undergraduate engineering education, much of the conversation around COVID-19 has neglected the degree to which students exhibit resilience and adapt to these changes. This study has provided a valuable snapshot of how students adapted to the constraints wrought by COVID. It demonstrated that students perceived that their learning experience was no different than that reported by students in previous pre-COVID offering of the capstone experience. Students were committed to seeing through their projects despite the various obstacles they faced due to the pandemic. This is especially commendable given that most of the students were graduating seniors and may have been facing the added pressure of uncertain job prospects in a pandemic economy. In the face of a global crisis, the students were proactive, creative, and resourceful as they designed around the constraints imposed by the pandemic. Student adaptations along with instructor-led adjustments in course expectations contradict the notion that the quality of college education was diminished by the transition to remote learning.

References

[1] T. A. Ghebreyesus, “WHO Director-General's opening remarks at the media briefing on COVID-19”, 11 March, 2020. [Online]. Available: https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020. [Accessed: 25-Feb-2021].

[2] C. Hodges, S. Moore, B. Lockee, T. Trust, and A. Bond, “The difference between emergency remote teaching and online learning” *Educause review*, vol. 27, pp. 1-12, 2020

[3] C. H. Tsai, G. R. Rodriguez, N. Li, J. Robert, A. Serpi, and J. M. Carroll, “Experiencing the Transition to Remote Teaching and Learning during the COVID-19 Pandemic”, *Interaction Design and Architecture(s) Journal*, pp. 70-87, 2020

[4] X. Wang, S. Hedge, C. Son, B. Keller, A. Smith, and F. Sasangohar, “Investigating mental health of US college students during the COVID-19 pandemic: cross-sectional survey study", *Journal of medical Internet research*, vol. 22, no. 9, pp. e22817, 2020

[5] C. Son, S. Hedge, A. Smith, X. Wang, and F. Sasangohar, “Effects of COVID-19 on college students’ mental health in the United States: Interview survey study”, *Journal of medical internet research,* vol. 22, no. 9, pp. e21279, 2020

[6] S. Brown, “COVID-19 Sent LGBTQ Students Back to Unsupportive Homes. That Raises the Risk They Won’t Return”, *Chronicle of Higher Education*, vol. 24, 2020

[7] L. A. Gelles, S. M. Lord, G. D. Hoople, D. A. Chen, and J. A. Mejia, “Compassionate flexibility and self-discipline: Student adaptation to emergency remote teaching in an integrated engineering energy course during COVID-19”, *Education Sciences*, vol. 10, no. 11, pp. 304, 2020

[8] K. Lee, M. Fanguy, X. S. Lu, and B. Bligh, “Student learning during COVID-19: It was not as bad as we feared”, *Distance Education*, pp. 1-9, 2021

[9] R. Kochhar, “Unemployment rose higher in three months of COVID-19 than it did in two years of the Great Recession”, *Pew Research Center*, 2020

[10] Accreditation Board for Engineering and Technology, Inc, “Criteria for Accrediting Engineering Programs, 2020 – 2021”. [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2020-2021/

[11] S. Howe, L. Rosenbauer, and S. Poulos, “The 2015 capstone design survey results: Current practices and changes over time”, *International Journal of Engineering Education*, vol. 33, no. 5, pp. 193, 2017

[12] L.J. McKenzie, M.S. Trevisan, D.C. Davis and S.W Beyerlein, “Capstone design courses and assessment: A national study”, *Proceedings of the 2004 American Society of Engineering Education Annual Conference & Exposition*, pp. 1-14, 2004

[13] S. Howe, R. Lasser, K. Su, and S. Pedicini, “Content in capstone design courses: Pilot survey results from faculty, students, and industry”, *American Society for Engineering Education*, 2009

[14] J.V. Farr, M. A. Lee, R. A. Metro and J. P. Sutton, “Using a systematic engineering design process to conduct undergraduate engineering management capstone projects”, *Journal of Engineering Education*, vol. 90, no. 2, pp. 193-197, 2001

[15] M. V. Jamieson, “Keeping a Learning Community and Academic Integrity Intact after a Mid-Term Shift to Online Learning in Chemical Engineering Design During the COVID-19 Pandemic”, *Journal of Chemical Education*, vol. 97, no. 9, pp. 2768-2772, 2020

[16] J. L. Wildman, D. M. Nguyen, N. S. Duong, and C. Warren, “Student Teamwork During COVID-19: Challenges, Changes, and Consequences”, *Small Group Research*, pp. 1046496420985185.

[17] J. R. Goldberg, “Identifying Alternate Resources and Adjusting Expectations for Senior Design Projects During the COVID-19 Pandemic of 2020”, *Biomedical Engineering Education*, vol. 1, no. 1, pp. 25-30, 2021

[18] J. W. Cresswell, and V. L. P. Clark, *Designing and conducting mixed methods research*. Sage publications, 2017.

[19] J. P. Stevens, *Applied multivariate statistics for social sciences*. Abingdon: Routledge, 2012.

[20] A. Field, *Discovering statistics using SPSS for Windows*. Thousand Oaks, CA: Sage Publications, 2000.

[21] A. B. Costello and J. Osborne, "Best practices in exploratory factor analysis: Four recommendations for getting the most from your analysis.," *Practical assessment, research, and evaluation,* vol. 10, no. 1, p. 7, 2005.

[22] S. B. Merriam, and E. J. Tisdell, *Qualitative research: A guide to design and implementation*. San Francisco, CA: John Wiley & Sons, 2015

[23] K. Charmaz, *Constructing grounded theory: A practical guide through qualitative analysis*. Thousand Oaks, CA: Sage, 2006

[24] D. D Nulty, "The adequacy of response rates to online and paper surveys: what can be done?", *Assessment & Evaluation in Higher Education*, vol. 33, no. 3, pp. 304-314, 2008

[25] A. Wigfield and J. S. Eccles, "Expectancy-value theory of achievement motivation," *Contemporary educational psychology,* vol. 25, no. 1, pp. 68-81, 2000.

[26] J. S. Cole, D. A. Bergin, and T. A. Whittaker, "Predicting student achievement for low stakes tests with effort and task value", *Contemporary Education Psychology*, vol. 33, no. 4, pp. 609-624, 2008

[27] M. T. Wang, and J. S. Eccles, "School context, achievement motivation, and academic engagement: A longitudinal study of school engagement using a multidimensional perspective", *Learning and Instruction*, vol. 28, pp. 12-23, 2013

[28] H. M. G. Watt, J. D. Shapka, Z. A. Morris, A. M. Durik, D. P. Keating, and J. S. Eccles, "Gendered motivational processes affecting high school mathematics participation, educational aspirations, and career plans: a comparison of samples from Australia, Canada, and the United States.", *Developmental Psychology,* vol. 48, no. 6, pp. 1594, 2012

[29] D. George, *SPSS for Windows step by step: A simple study guide and reference, 17.0 update,* Boston: Allyn & Bacon, 2009