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The Effects of COVID-19 on Mechanical Engineering Senior Capstone Design Student Self-efficacy and Projects

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Abstract

As a result of the COVID-19 pandemic in 2020, protocols were put in place at universities in an effort to keep students, faculty, and staff safe. At Texas A&M University, many traditional face-to-face lectures transitioned into an online format, and facilities, like makerspaces, implemented safety guidelines with occupancy limits and reservation requirements. The changes affected the mechanical engineering senior design students in multiple ways from instructional format to meeting format to prototyping capabilities. In this study, we seek to better understand the effects of these changes on the senior design students.

In Fall 2020, senior design students completed an exit survey to assess their engineering design self-efficacy, or belief in their own ability to complete design tasks. Self-efficacy affects a person's behavior, and those with high self-efficacy will put forth increased effort, perseverance, and persistence to achieve their goals. Since experience affects engineering design self-efficacy, there was concern that students would not achieve the same level of self-efficacy with the adjusted projects. This study examines how COVID-19 has shaped the students' capstone experience and their resulting self-confidence. The study found that engineering design self-efficacy was not correlated to instructional format. While a majority of the students noted that they had a project plan change due to COVID-19, most still felt that they were able to complete their project. There was no significant difference in self-efficacy of those that noted a project change and those that did not. The Fall 2020 survey data was then compared to a previous non-COVID-19 semester's data. There was no statistically significant difference in engineering design self-efficacy or effort put forth on the project between the two groups. Surprisingly, the Fall 2020 COVID-19-affected group had a marginal increase in overall senior design project satisfaction.

Introduction

In the Spring 2020 semester, significant educational changes were made throughout the world as a response to the COVID-19 pandemic. Classes pivoted from the conventional face-to-face format to an online format for the safety of the students, faculty, and staff. Some classes were able to move online easily, but there were concerns regarding the ability to convert a team-based hands-on engineering senior capstone design course. The capstone courses are meant to be an experiential project to help students bridge the gap between academic coursework and industry. The course relies heavily on teamwork, and many teams conduct hands-on work. Texas A&M University's mechanical engineering department has a two-semester senior design program where students work in teams of four to seven on a sponsored senior design project. One of the goals of the program is to produce students with a high engineering design self-efficacy, or belief in their own ability to conduct design. In Fall 2020, students were able to return to campus although strict COVID-19 safety guidelines and restrictions were in place. Students had limited access to on-campus resources to build and test prototypes, which sometimes resulted in changes to their design validation plans. Some students chose to complete the course completely online for their safety. There were concerns that students would not able to receive a true senior design experience and the resulting strong belief in their design abilities. In this paper, we examine the effects of the COVID-19 changes on the mechanical engineering senior capstone design students' engineering design self-efficacy and their project experience.

Background

1. An Introduction to Self-Efficacy

Self-efficacy is one's belief about their own ability to successfully achieve a particular goal or skill. The framework was first introduced by Bandura in 1977 [1]. A person's self-efficacy is important because it affects their attitude and behavior. Those with high self-assurance have a strong belief in their abilities. When encountering an obstacle, they will see it as a challenge to be conquered and will continue to persist in overcoming the problem. They set challenging goals for themselves and will put forth increased effort to achieve them. They are able to recover their sense of efficacy quickly after setbacks and failures [2]. With this behavior, those with high self-efficacy have an increased likelihood of success [3].

Studies have shown that self-efficacy is a positive predictor for a person's ability to achieve their goals [3-8]. In fact, research has found that these efficacy beliefs can better predict achievement of future accomplishments than examining the previous accomplishments alone [9, 10]. When trying to help students learn and develop, it is important to consider their beliefs about their skills in addition to their ability to master the skill. Students' self-efficacy is highly related to motivation and achievement, and is a predictor for academic success [3, 6-8, 11-13].

Within engineering specifically, engineering self-efficacy has been found to be positively related to students' achievement. Students with a high level of engineering self-efficacy try to learn new skills, which when mastered can then increase their belief in their abilities [14]. General engineering self-efficacy has been found to be a strong predictor for GPA [15]. Problem-based learning (PBL) research has found that engineering self-efficacy can be improved through a project-based course like capstone [16, 17]. However, engineering self-efficacy is dependent on the engineering experience [18].

2. COVID-19 Pandemic Effects in Education

With the COVID-19 pandemic, students experienced disruptions to their education, which included reduced schedules, online instruction, and full school closures. At its peak, UNESCO reported that over 1.6 billion students were affected worldwide [19]. Even in January 2021, one year into the pandemic, over half of the world's enrolled learners are still experiencing significant disruptions to their education [20].

Asgari et al. conducted a COVID-19 College of Engineering student survey at California State University Long Beach to learn more about the effects of engineering online education. They found that only 24% of the students found the overall online instruction experience to be satisfying. Some of the common concerns including difficulty maintaining focus through multiple Zoom courses, social disconnection from fellow students, lack of engagement in online classes, and technical difficulty with the technology [21].

In Spring 2020, many students in engineering capstone programs faced significant challenges during university shutdown because they lost access to makerspaces and equipment needed to complete their projects. While campuses were closed, students either worked independently on their projects at their residence or they modified final deliverables to no longer center on a functioning prototype. Goldberg discussed adjusting expectations for his biomedical engineering capstone program. Almost half of his teams were still able to complete their prototype, but the others shifted to non-functional prototypes or non-functional scale models [22]. In the ASEE 2020 Making it work in the Virtual Capstone Climate and Beyond DEED Panel, a survey of capstone faculty found that physical prototypes were a concern and necessitated a need to modify requirements to accommodate construction challenges. CAD models, online simulations, additional analysis, and build plans were common replacements for the physical prototypes. In addition to the construction constraints, Jaeger-Helton found that her online capstone students found it challenging to collaborate for meetings and classwork, as well as connecting in general [23].

Texas A&M's Mechanical Engineering Senior Capstone Design Program and COVID-19 Guidelines

In mechanical engineering senior capstone design programs, instructors aim to bridge the gap between classroom and industry to help students develop the knowledge and skills needed to become practicing engineers. In this research study's program, the students work in teams to solve an open-ended, real-world design problem for a client over the course of two semesters. The projects are sponsored by industry, national laboratories, faculty members, and the local community. In MEEN 401 Introduction to Mechanical Engineering Design in the first semester, students complete a needs analysis, generate concepts, and select a solution. In MEEN 402 Intermediate Design in the second semester, students are required to verify and validate their concept, which is typically through prototyping/testing, computational analyses, calculations, and/or comparison to literature. Both classes have a lecture and studio portion. In lecture, the general design process, design methods, and other topics are taught to a class of approximately 100 students. In each studio, three to five teams apply the design process to their specific project under the guidance of their studio instructor. Each studio meets for three hours per week.

In the first half of the Spring 2020 semester, the first-semester MEEN 401 students had a typical experience. Their course was taught in person. and the teams were able to meet face-to-face to work on projects. In March 2020, the students left for spring break. They were informed at the end of their break that there would be a move to online classes for the remainder of the semester. Students in the capstone program were told that they should not go to campus for any reason, including the fabrication of parts for their projects or group work. At that point in the semester, the MEEN 401 teams were generating concepts for their project and completing concept selection. The remainder of the semester was conducted online. Most of the lectures and studio meetings took place synchronously through Zoom, and teams shared information via their Google Team Drive. The teams completed embodiment design, validation planning, and cost modeling in an online format. The teams were instructed to develop two separate plans for their Fall 2020 MEEN 402 second semester – one if things improved and one if things remained as is. With the potential for a remote second semester, studio instructors suggested that teams consider more analytical work rather than physical prototype construction. The need for flexible project management and modular validation was stressed.

In Summer 2020, another group of students took the first-semester senior design course, which was offered fully online. There were 27 students in the class, and they worked on five different projects. These students also took their second semester of senior design in Fall 2020.

In Fall 2020, students were able to return to campus, but with strict safety protocols in place. No student was required to physically be on campus. Everyone on campus was required to wear a mask and physically distance at least six feet. The second semester senior design lectures were conducted synchronously remote via Zoom. The second semester studio had a face-to-face option, but most students chose to attend remotely using the active live streaming Zoom studio session. Additional capstone guidelines provided by the College of Engineering included no course-related travel away from campus; no in-person, on-campus meetings outside of the scheduled course meetings; and no in-person, off-campus meetings. Students could use lab facilities elsewhere if the facility was located on the primary campus, the facility was operating in compliance with COVID-19 requirements, the student was working individually, and the student was proctored by a trained, independent person. The commonly used makerspace, Fischer Engineering Design Center (FEDC), and the undergraduate laboratories had occupancy limitations and scheduling requirements such as a 48-hour reservation process. Students were encouraged to submit FEDC fabrication requests rather than machining parts themselves due to these protocol constraints.

Design Self-Efficacy and Project Feedback Survey Instrument

In the final three weeks of each semester, the second-semester senior design students are invited to participate in an online engineering design self-efficacy and project feedback survey. The survey is voluntary and has no impact on the students' grades.

The Carberry Design Self-Efficacy Instrument was used to measure the students' beliefs in their design abilities. The 36-item survey has been validated for content, criteria, and construct [18]. It considers the four task-specific self-concepts of self-confidence, motivation, expectancy of success, and anxiety towards the task. Someone with high engineering design self-efficacy would be confident and motivated to do engineering design with a high expectancy of success and low level of anxiety [24]. For each of the self-concepts, nine tasks are considered. The first task relates to conducting engineering design as a whole. The other eight tasks were based on the Massachusetts Department of Education engineering design process to ensure the research participant considers each step of the design process. The confidence self-concept portion of the survey can be found in Table 1.

In addition to the Carberry Design Self-Efficacy instrument, the survey included questions about the student's project experience. In Fall 2020, new questions were added to learn about the effects of the COVID-19 on the student's particular project. The project survey questions that are examined in this paper are:

1. "How did you attend MEEN 401 lecture?" Face-to-face, Hybrid/Both, Online
2. "How did you attend MEEN 402 studio?" Face-to-face, Hybrid/Both, Online

3. "Did your project plans change due to COVID-19?" Yes, No
4. "Were you able to complete your project?" Yes, No
5. "On average, approximately how many hours per week did you spend on your project (not including lecture)?" Under 4 hours, 4-8 hours, 8-12 hours, 12+ hours
6. "Indicate your level of agreement with the following statement: I was satisfied with my senior design project." Strongly disagree, Disagree, Neutral, Agree, Strongly agree

Table 1. An example of one of the questions in the design self-efficacy survey: "Rate your degree of CONFIDENCE (i.e. belief in your current ability) to perform the following tasks by recording a number from 0 to 100. (0 = cannot do at all; 50 = moderately can do; 100 = highly certain can do)."

	0	10	20	30	40	50	60	70	80	90	100
conduct engineering design											
identify a design need											
research a design need											
develop design solutions											
select the best possible design											
construct a prototype											
evaluate and test a design											
communicate a design											
redesign											

Analysis, Results, and Discussion

The survey responses were analyzed after the students graduated. If a student had multiple survey submissions, only the latest one was used. In Fall 2019, there were 94 survey responses. In Fall 2020, there were 72 survey responses. For Carberry's survey instrument, the nine design tasks were averaged for each self-concept.

1. Comparison Within the Fall 2020 Survey Data

a) Design Self-Efficacy to Course Format

In the senior design lectures, the lecture instructor teaches the design process. The class has a heavy emphasis on active learning and discussion. Many in-class activities requires teams to work together for assignments, which help to improve team dynamics. In Spring 2020, the first-semester MEEN 401 students began with face-to-face instruction, but moved to an online class midway through the semester. In Summer 2020, the MEEN 401 students only attended lecture online. There was a different lecture instructor for the two MEEN 401 lectures, but both instructors have been part of our senior design program and worked off of the same slide deck. Since the corresponding MEEN 401 studio was conducted in the same format as lecture (hybrid in spring, online in summer), only the MEEN 401 lecture format was compared to self-efficacy.

A two-sample t-test assuming unequal variances was conducted for each of the self-concepts between those that attended MEEN 401 with a face-to-face component and those that attended online only. The lecture format for MEEN 401 did not have an effect on the senior design students' self-efficacy. There were no statistically significant difference for the four self-concepts (Table 2) with a minimum p-value of 0.423.

Table 2. Self-concept means and standard deviations for those that reported attending MEEN 401 lecture face-to-face or in a hybrid format compared to those attending online only with independent samples t-test results.

	Face-to-Face/Hybrid		Online Only		t-test	
	M	**SD**	**M**	**SD**	**t-value**	**p-value**
Confidence	83.0	14.5	83.9	21.6	-1.266	0.853
Motivation	80.0	17.7	80.2	18.7	-0.031	0.976
Success	82.0	12.3	85.3	17.0	-0.812	0.423
Anxiety	35.9	26.2	35.0	29.1	0.126	0.901

In the second-semester MEEN 402 senior design class, teams validate their designs, which typically requires more hands-on work. All students were in the same online synchronous MEEN 402 lecture. However in Fall 2020, students were given the opportunity to attend studio face-to-face. Only 12 students marked that they attended studio either "face-to-face" or "hybrid/both". Once again, there was no statistically significant difference in the four self-efficacy self-concepts using an unequal variance two-sample t-tests (Table 3).

Table 3. Self-concept means and standard deviations for those that reported attending MEEN 402 studio face-to-face or in a hybrid format compared to those attending online only with independent samples t-test results.

	Face-to-Face/Hybrid		Online Only		t-test	
	M	**SD**	**M**	**SD**	**t-value**	**p-value**
Confidence	88.6	12.4	82.0	17.4	1.553	0.135
Motivation	81.3	13.8	79.9	18.4	0.308	0.762
Success	86.2	12.4	82.4	14.1	0.898	0.384
Anxiety	30.6	25.7	37.3	27.4	-0.817	0.425

The lack of an effect due to instruction format and instructor on self-efficacy was interesting to note. The absence of a difference could be because the students simply learn the methods in class, but gain self-efficacy through their experience of applying the information to their project. This would be consistent with a previous study, which found that engineering design self-efficacy is correlated to student effort and experience rather than external factors such as sponsor type, validation method, and amount of sponsor guidance [25].

b) Design Self-Efficacy to COVID-19 Project Change

Students were asked if they had to make changes to their project due to COVID-19. Fifty-one students selected "yes" and 21 students selected "no". Independent samples t-tests were conducted for the four self-concepts. Once again, there was no statistically significant difference between those that believed they had a project change and those that did not (Table 4). However, the average of those that noted a project change had a higher confidence and motivation than those that marked no change (Figure 1). Interestingly, 13 of the 18 teams had students on the team mark a combination of yes and no. Only five teams had everyone agree that there was a change to their project plan.

Table 4. Self-concept means and standard deviations for those reporting no project change due to COVID-19 and those reporting a change with independent samples t-test results.

	No Change		**Change**		**t-test**	
	M	**SD**	**M**	**SD**	**t-value**	**p-value**
Confidence	78.2	22.3	85.0	13.6	-1.309	0.202
Motivation	74.4	21.6	82.0	15.5	-1.461	0.155
Success	81.7	16.2	83.3	12.9	-0.387	0.701
Anxiety	36.4	23.0	36.6	28.8	-0.035	0.972

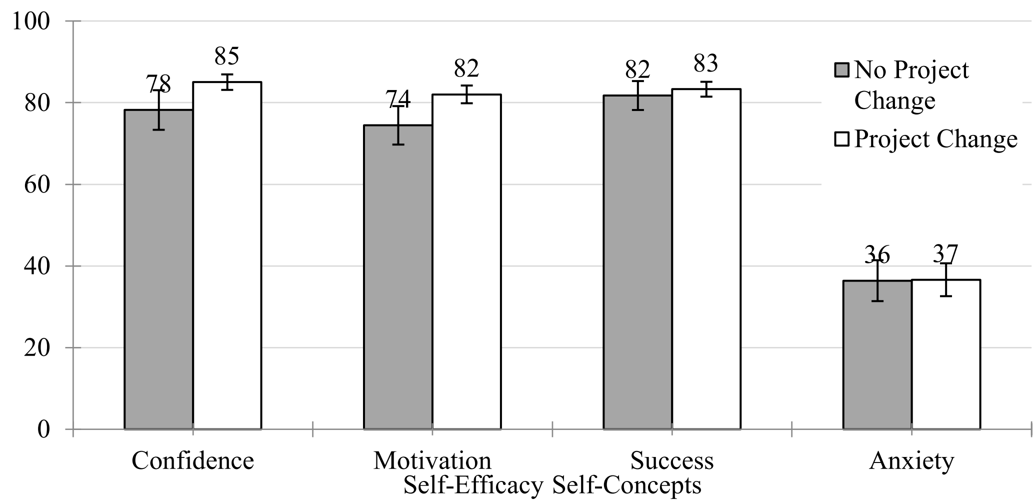

Figure 1. Mean engineering design self-concept scores for those that reported no project change (gray) and those that reported a project change (white) due to COVID-19. Error bars show ±1 standard error.

c) Project Completion

Only four of seventy (5.7%) students reported that they were not able to complete their project. With such a small sample size, a statistical analysis could not be completed. The four respondents were from different projects with different project validation formats and different reported weekly effort levels. Their self-efficacy instrument responses were also very inconsistent. For the task of "Conduct engineering design" in the "Confidence" self-concept, their mean was 75 and standard deviation was 23.8.

However, it is worth noting that a majority of the students that identified a project change due to COVID-19 felt that they completed the project successfully. This points to the importance of communication within the team and with the sponsor and studio instructor. Through discussion and planning, teams were able to identify new tasks and project deliverables. This allowed students to have an achievable senior design experience despite the necessitated changes.

d) General Project Changes

After speaking with the teams and their studio instructors, there were some notable differences with this cohort's validation plans. There was more emphasis on analysis and nonphysical modeling to validate the designs compared to previous semesters. In an informal, anonymous survey of MEEN 402 students in late September, 53 of the 77 respondents (69%) noted that they were doing some form of prototyping. However, in order to have a hands-on experience while following COVID-19 guidelines, the prototyping work changed. Instructors noted that some teams were doing smaller proofs of concept rather than the full-scale prototypes they initially planned. Other teams focused more on assembly by buying more off-the-shelf parts and submitting fabrication requests to the makerspace machine shop rather than machining parts themselves. All of the teams that produced a prototype also completed additional forms of analysis.

2. Comparison of Fall 2020 Survey Data to Fall 2019 Data

The Fall 2020 data was compared to the Fall 2019 survey data. The Fall 2019 group had a typical semester and was not affected by COVID-19. A fall group was chosen for comparison because the students were more likely to be similar at the start. Fall second-semester senior design students typically have a longer time to graduation and are part of a smaller senior design class.

a) Overall Design Self-Efficacy Comparison

First, the engineering design self-efficacy was compared between the Fall 2019 and Fall 2020 groups. Independent samples t-tests found that there was no statistically significant difference between the two groups' self-concept scores (Table 5). The Fall 2020 senior design students were still able to obtain a high level of engineering design self-efficacy despite the effects of COVID-19 and changes to their project plans.

Table 5. Self-concept means and standard deviations for Fall 2019 and Fall 2020 MEEN 402 students with independent samples t-test results

	Fall 2019		**Fall 2020**		**t-test**	
	M	**SD**	**M**	**SD**	**t-value**	**p-value**
Confidence	80.1	11.4	83.0	16.7	-1.27	0.208
Motivation	78.6	14.4	79.8	17.7	-0.47	0.640
Success	79.8	12.8	82.8	13.8	-1.42	0.159
Anxiety	41.2	26.1	36.6	27.0	1.11	0.270

b) Overall Effort Comparison

Students from both semesters were asked to identify the average hours per week spent on project-related work outside of lecture and studio. The self-reported response options were <4 hours, 4-8 hours, 8-12 hours, and 12+ hours. The four responses were converted to a four-point scale and an independent samples t-test was used to compare the two groups. There was not a significant difference in the reported effort put forth by the Fall 2019 and Fall 2020 MEEN 402 senior design students $t(155) = 0.236$, $p = 0.813$. Although the type of work completed may have been different, the Fall 2020 group still put in significant effort to have a satisfactory senior design project. This may be because students have a different perspective of the senior design course compared to their other classes. Second-semester MEEN 402 students are invited into MEEN 401 lecture for "402 Advice Day" to provide suggestions to help the first-semester students plan and prepare for their final semester. When one second-semester team was asked about their mentality balancing 402 with other coursework, they said that they treated the class differently than typical classes. They said that "This class is the closest you will get to a real-world job… It's different and extremely time-consuming, but you care about it a lot and are willing to put in more effort." From this coordinator's perspective, this mentality has remained consistent even with all of the changes.

c) Overall Project Satisfaction Comparison

The students were asked about their overall satisfaction with their senior design project. The response options were strongly unsatisfied, unsatisfied, neutral, satisfied, and strongly satisfied, which were converted to a five-point scale for analysis. With an independent samples t-test, there was a marginal difference in project satisfaction ($t(155) = -1.78$, $p = 0.077$) between the Fall 2019 students ($M = 3.56$, $SD = 1.24$) and the Fall 2020 students ($M = 3.89$, SD 1.11). Additional research needs to be completed in order to better understand the average satisfaction increase for the COVID-19 affected senior design students. This increase could be due to the different projects and sponsors. Another possibility is that the COVID-19 changes allowed the students to have a better experience. The teams gained a deeper understanding of project management, project planning, and developing flexible contingency plans. The students were also encouraged to increase communication with each other, their studio instructors, and their sponsors to keep everyone informed as changes took place. Finally, studio instructors and sponsors were asked to be more flexible with the team considering the circumstances. As a whole, they were very supportive and willing to change project expectations to help the students succeed. This environment may have also helped the teams feel more positively toward their project. While I can only speculate as to the causes of the slight increase, it is reassuring to know that the students can still have a satisfactory, successful senior design experience even when receiving changing directives and trying to adapt to different guidelines.

Conclusions

In this study, we examined the students taking their mechanical engineering senior capstone design courses during the COVID-19 pandemic. There were significant changes made to the program including instructional format and project work guidelines. This resulted in students having a different senior design experience and required many teams to make changes to their project plans. However, there was not a statistically significant difference when comparing engineering design self-efficacy to class format or project plan changes due to COVID-19. An comparison of the Fall 2020 group to a previous non-COVID-19 semester found that there was no statistically significant difference in overall design self-efficacy or level of effort put forth by students. When comparing the two semesters' data, there was a marginal increase in project satisfaction for the COVID-19 Fall 2020 class. A main takeaway is that the students are very resilient and can adapt to changes. The students can still have a good experience and obtain high design self-efficacy by taking ownership of their projects and putting in the effort. As instructors, we can worry less about the COVID-19 programmatic effects on our senior design students, and focus our attention on supporting the students and giving them the opportunity to do the work. From a coordinator perspective, the students are still developing ambitious design validation plans while learning more about project management and the need for flexibility and contingency. Future research work includes continuing to conduct the survey to learn more about the student experience. Future surveys should also be updated to ask more questions about the project changes made due to COVID-19. With more feedback on the changes, we can identify if specific project changes have a greater impact on design self-efficacy and project satisfaction. This can help capstone coordinators to scope projects appropriately and provide better guidance to senior design teams if the need for remote and hybrid courses are necessary in the future.

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