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Effects of Pedagogical Changes to an Engineering Capstone Course During the COVID-19 Pandemic

Dr. Michael Daniel Sherwin P.E., University of Pittsburgh

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Effects of Pedagogical Changes to an Engineering Capstone Design Course During the COVID-19 Pandemic

Michael D. Sherwin
Assistant Professor of Industrial Engineering
University of Pittsburgh

Bopaya Bidanda
Ernest E. Roth Professor & Chairman
Department of Industrial Engineering
University of Pittsburgh

Abstract

The COVID-19 pandemic forced colleges and universities with the challenge of converting courses mid-semester to remote instruction. Instructors were forced to evaluate and modify existing pedagogical approaches. Capstone Design courses were not immune to these changes and presented a set of unique challenges as institutions and businesses alike moved to remote modes of operation. Capstone Design courses are an integral part of engineering education and prepare students for engineering practice through culminating design experiences. Such courses provide an opportunity to apply both qualitative and quantitative techniques to solve real problems facing industry sponsors. This study evaluates the effects of changes made in delivering an Industrial Engineering Capstone Design course amid the COVID-19 pandemic. Specifically, student feedback, course assessments, and performance are compared across multiple semesters and analyzed for the mode of course delivery (face-to-face, hybrid, and online) and the course design changes. Students participated in an online survey to gather their perspectives beyond standard course evaluations and test the hypothesis that the mode of delivery did not influence student learning outcomes. Survey results are supplemented by course evaluations and student performance to determine if changes in the course affected the student experience.

1 Introduction

Like many of their peers in other engineering disciplines and at other universities, Industrial Engineering students at the University of Pittsburgh culminate their undergraduate experience with a Capstone Design Course (IE1090). The course provides students with a hands-on learning experience in a relatively unstructured environment as they prepare to enter the workforce as practicing engineers. Course outcomes and curriculum align with Criterion 3 and Criterion 5 of the *ABET Criteria for Accrediting Engineering Programs* [1]. Students enrolled in the class, which is traditionally offered each Spring and Fall term, are matched in teams consisting of 4-6 students and tasked with solving a relevant industry problem identified by a sponsoring company. A member of the Industrial Engineering faculty is assigned to each team and serves as a mentor. Faculty mentors are matched to projects that align with their respective areas of expertise. Approximately 40-students are enrolled in the course each semester.

The course instructor introduces students to their respective team assignments during the initial class meeting and provides an overview of the course organization, expectations, and lessons learned from previous semesters. After the initial class meeting, students are responsible for the project's overall management, including coordinating with the sponsor's point of contact and their assigned mentor, determining roles and responsibilities within the team, and setting a weekly communication cadence via meetings and weekly reports. Student teams initially focus on developing a project proposal, which the client sponsor must approve. Throughout the semester, each group presents status updates to the class and faculty. At the end of the semester, teams give a final presentation with classmates, sponsors, faculty, and guests in attendance. Also, teams write and submit a final report and participate in a Design Expo that includes Capstone Design teams from all engineering disciplines across the University. The final report and presentation, the quality and professionalism of project management documentation, peer assessments, and sponsor feedback contribute to the student's final grade.

The COVID-19 pandemic forced Colleges and Universities to modify the mode of course delivery. In March 2020, the University of Pittsburgh initially offered courses in a 100% remote format. Subsequently, it introduced "Flex@Pitt"—a flexible instructional model that offers both in-person and remote teaching and learning options based on the University's operational posture [2]. Like many other courses, the Industrial Engineering Capstone Design course needed to pivot to a remote-learning mode of delivery. The change in modality was specifically challenging for this course, given that both students and client sponsors were adapting simultaneously to the difficulties posed by the then-new pandemic environment.

While the pandemic was and has since been an arduous experience for so many, it provided a learning opportunity for students, faculty, and sponsors alike. When the Spring 2020 term re-started, students were assigned to develop a continuity of operations plan for their project [3]. Companies and government agencies use the continuity of operations plan to ensure that mission-essential functions continue through emergencies. By developing continuity of operations plans, students were provided additional insight into project management during an emergency.

Besides providing students the opportunity to learn new project management tools, the pandemic also offered students the chance to develop leadership competencies beyond what is enhanced ordinarily. Examples of competencies include being action-oriented, managing ambiguity, managing complexity, managing conflict, driving for results, optimizing work processes, and several others. [4]

Although typically an unstructured and student-centered course that challenges students to solve the problems presented to them independently, additional structure and guidance were provided to students beginning in Summer 2020 to support the shift to a remote learning environment. Examples include the following: (1) supplemental lectures on the use of project management tools, communication, and team dynamics; (2) assessments and subsequent discussions to facilitate improved teamwork; and (3) support in setting up and conducting remote meetings. Historically, projects were limited geographically to a reasonable driving distance from campus so that students could visit the sponsor as needed. While the shift to remote learning created a challenge in this respect, it also provided an opportunity to expand the geographical reach of sponsors beyond the greater Pittsburgh area. Furthermore, students and sponsors developed creative mechanisms to communicate, meet, and observe the company operations. Moreover, the pandemic created a situation that resulted in some students not returning to campus, which left student teams spread across several time zones and regions of the world. While the changes caused by the COVID-19 pandemic presented significant challenges, the situation also presented new opportunities for students to practice skills that were not part of the curriculum previously and will serve them well as they enter the workforce as practicing engineers.

The literature includes several studies on both online and capstone courses, but few are focused on online capstone courses and make improvements in a short timeframe based on student feedback within an environment like the COVID-19 pandemic. Many authors discuss the process used to deliver a capstone course [5], align the capstone course with ABET criteria [6], and propose alternative approaches to implement capstone courses [7]. Haslam and Beck [8] studied the preparedness for students to work in teams during capstone projects and recommended instruction to close the gaps of their findings. However, the authors did not address the challenge of navigating these gaps during capstone courses delivered in an online environment. In the University of Pittsburgh Industrial Design Capstone course discussed in this paper, we also identified this need and provide for additional instruction in these areas from semester to semester.

The literature on course development, student engagement, and course delivery in an online environment is abundant. However, few authors address senior design capstone courses within their work. Although not a senior design capstone course specifically, Berry [9] discusses teaching a hands-on course, electrical circuits, in an online environment and recommends best practices. Similarly, Sabuncu and Sullivan [10] outline the delivery of a project-based course in mechanical engineering. The authors also employed student feedback to gauge the student experience. Considine [11] discusses strategies for developing effective online courses but does not address the topic of capstone courses.

To assess the impact of the shift in modality on the student experience and subsequently use the feedback to maintain and enhance the student experience as we advance through the COVID-19 pandemic and beyond, the authors used a general class survey and collected data from students enrolled in the course beginning in Spring 2020. This paper presents the results and initial analysis of data gathered from students enrolled in the Industrial Engineering Capstone Design course during the Spring 2020, Summer 2020, and Fall 2020 terms. Section 2 of this paper includes a description of the methods used, summarizes the data, and presents the data analysis. Section 3 discusses the study results, and Section 4 provides summary conclusions and outlines a plan for future work. In Section 5, we propose future research to further develop this work.

2 Methods

Changes to the course were made due to the shift to the remote learning modality and students' feedback throughout the semester. Some modifications were made between semesters, while other changes occurred within the semester (e.g., continuity of operations plans). In addition to the changes, enhancements were made to some course elements to provide additional structure and support for students. Table 1 summarizes the course structure's primary changes between and within the three semesters that are part of this paper's scope. Further, Table 1 illustrates the elements of the course that were sustained across periods.

Table 1. Summary of changes made to the course.

Description	**Spring 2020**	**Summer 2020**	**Fall 2020**
In-Person Sponsor Visits/Meetings	○	□	●
In-Person Team Meetings	○	□	□
Peer Evaluations	●	●	●
Self-Evaluations	●	●	●
Continuity of Operations Plans	○	□	□
Remote Sponsor Visits/Meetings	○	●	●
Remote Team Meetings	○	●	●
Supplemental Lectures	□	●	●
Team-Building Assessments	□	●	●
Detailed Course Schedule	□	□	●
Supplemental Checklists	□	□	●
In-Person Presentations	○	□	□
Remote Presentations	○	●	●
Final Report	●	●	●
Design Expo	□	□	●

KEY: ● – full semester | ○ – modified within semester | □ – not offered/not required

Some course elements were unchanged by the shift to remote learning and included student peer evaluations, student self-evaluations, and the requirement to submit a final team report at the end of the semester. Remote interactions replaced face-to-face meetings, visits, tours, and presentations during the Spring 2020 semester and continued into Summer 2020 and Fall 2002. Beginning in Fall 2020, some teams visited their sponsor companies. Students were not required to visit sponsor sites as part of the course. Visits were only conducted when companies had adequate COVID-19 protocols and when students and sponsors were comfortable doing so. For most projects, photographs and videos provided by the sponsor replaced in-person visits. Projects were selected in Summer 2020 and Fall 2020 based on their ability to be conducted entirely remotely.

Team-building assessments were introduced in Summer 2020 and continued in Fall 2020. The assessments helped students gain better self-awareness and leverage teammates' strengths and the team's diversity overall. After completing the assessments, students were given time during supplemental lectures to discuss their respective teams' results. While not meant as a replacement for the benefits of face-to-face interaction, the assessments provided an opportunity for the teams to get to know one another better and increase the group's productivity when working in a remote environment.

Students indicated that remote learning created challenges in meeting with their teammates and communicating overall. Furthermore, the course expectations in a face-to-face setting were not as applicable once the course moved to a remote format. To provide more explicit expectations, the course Syllabus was modified beginning in Summer 2020 to include more details regarding the course schedule and deliverables throughout the semester. Furthermore, students were provided supplemental checklists to ensure that teams were meeting ABET Criterion 3 course outcomes as their projects progressed. Further, teams were provided industry-based project management templates so that the coursework focused on solving the clients' problem and less time was spent having to determine how to organize the project. Lastly, a focused effort was made to solicit the appropriate number of quality projects to reduce the average team size from more than six students per team (Spring 2020) to an average of four students per team. Smaller team sizes were found to improve the distribution of tasks throughout the team and improve overall communication.

In addition to the standard teaching assessment and student feedback surveys completed ad hoc throughout the semester, a survey was developed and distributed to students enrolled in the Industrial Engineering Capstone Design course at the end of each of the Spring 2020, Summer 2020, and Fall 2020 terms. The survey consisted of twelve questions to determine the impact that the remote environment had on the course outcomes, the students' overall learning experience, and student preferences (see Table 2). Responses were collected using Likert scales, multiple-choice, and free-text formats.

Table 2. Survey questions.

Question	Response Type
Course Outcomes and Curriculum	
Q1. How relevant was this course in preparing you for a career as an Industrial Engineer?	Likert Scale
Q2. Which three Industrial Engineering undergraduate courses were most helpful in preparing you to successfully complete your project?	Multiple Selection
Q3. Did you consider the use and application of appropriate engineering standards in your project?	Multiple Choice
Q4. Can your project be classified as a complex engineering problem?	Multiple Choice
Q5. Did you work with realistic constraints?	Multiple Choice
Learning Experience	
Q6. Did the idea of a virtual capstone course hinder your learning?	Multiple Choice
Q7. How useful was this course in learning how to work as a team?	Likert Scale
Q8. How useful was this course in solving a real-life engineering problem?	Likert Scale
Q9. How useful was this course in dealing with professionals in an engineering environment?	Likert Scale
Q10. Was completing the course online a hindrance in developing an appropriate solution to your team solving the problem that you were given?	Multiple Choice
Student Preferences	
Q11. Describe what you liked most about this course.	Descriptive
Q12. Describe what you liked least about this course.	Descriptive

3 Results and Discussion

Enrollment in the Industrial Engineering Capstone Design course varies by semester and ranges between 35 and 45 students, with the highest registration typically occurring in the Spring semester. The department does not traditionally offer the course in the Summer semester. However, due to the extenuating circumstances presented by the COVID-19 pandemic, it was made available in 2020 to provide students an opportunity to reduce their workload during the coming Fall and Spring semesters. The survey's response rates varied across the three semesters studied, with the highest response rates occurring in Summer 2020 (77.8%) and Fall 2020 (85.7%). Table 3 summarizes the 2020 course enrollment and survey response statistics.

Table 3. Summary of 2020 course enrollment and survey response statistics.

Semester	Spring 2020	Summer 2020	Fall 2020
Enrollment	56	9	35
Projects	9	2	9
Students per Project	6.22	4.50	3.89
Survey Responses	20	7	30
Survey Response Rate	35.7%	77.8%	85.7%

Depending on the type of response to the specific question, the survey results were analyzed using summary statistics (all questions), net promoter scores (Likert scale), hypothesis testing (multiple choice and Likert scale), and word cloud analysis (descriptive). The results of the analysis of each question are described in the sections that immediately follow.

3.1 Course Outcomes and Curriculum

Students were asked a total of five questions related to the course outcomes and curriculum directly related to ABET Criterion 3 and Criterion 5. A net promoter score (see Equation 1) was derived to summarize students' responses to how relevant the course was in preparing them for a career as an Industrial Engineer (Q1). Within-semester net promoter scores were compared using a Fisher's Exact Test to determine if a statistical significance existed between semester responses [5]. By comparison, the students enrolled in the Summer and Fall semesters responded more favorably than those who responded in the Spring semester. However, the differences in net promoter scores across semesters were not statistically significant at a 95% confidence level ($\alpha = 0.05$). Figure 1 illustrates the responses to the question and Table 4 presents the net promoter scores and corresponding p-values for the Fisher's Exact Test.

$$NPS_A = [\%ER + \%MR] - [\%SI + \%MI + \%EI] \qquad \textbf{Equation 1}$$

Where: NPS is Net Promoter Score
$\%ER$ is the percentage of respondents responding "Extremely Relevant"
$\%MR$ is the percentage of respondents responding "Moderately Relevant"

$\%SI$ is the percentage of respondents responding "Slightly Irrelevant"
$\%MI$ is the percentage of respondents responding "Moderately Irrelevant"
$\%EI$ is the percentage of respondents responding "Extremely Irrelevant"

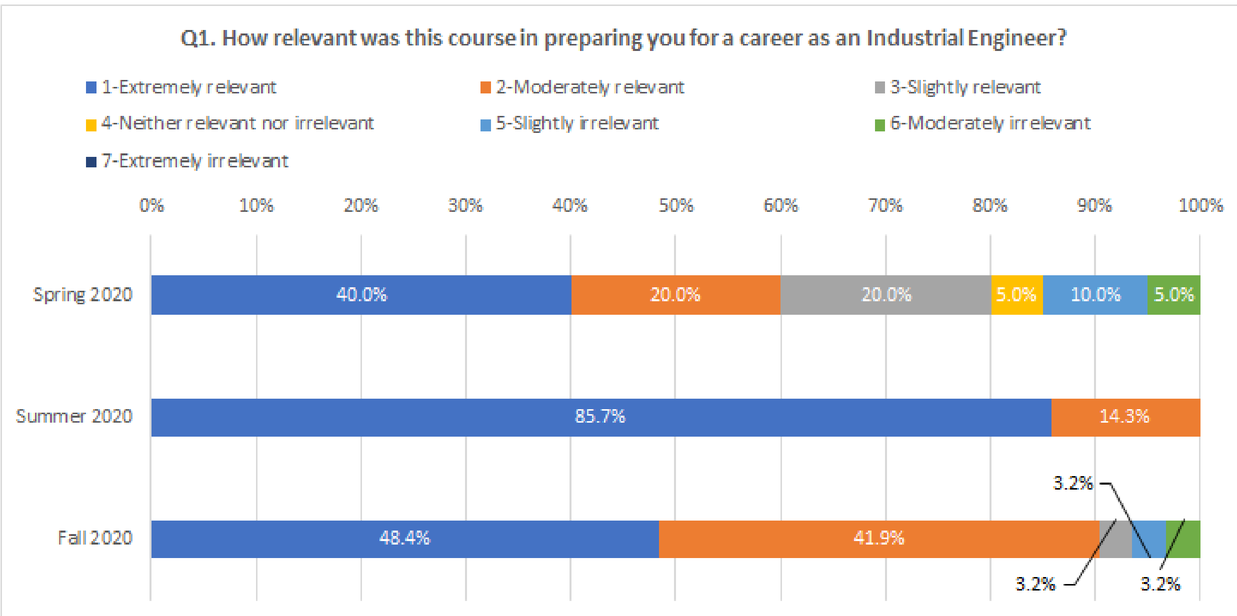

Figure 1. Summary of responses to Q1.

Table 4. Fisher's exact test p-values and net promoter scores for Q1 (95% significance level).

Semester	**Spring 2020**	**Summer 2020**	**Fall 2020**
Spring 2020	--	--	--
Summer 2020	$p = 0.068$	--	--
Fall 2020	$p = 0.015$	$p = 1.000$	--
Net Promoter Score (NPS_A)	45.0%	100.0%	83.9%

When asked which courses were most helpful in preparing students to complete their Industrial Engineering Capstone Design project successfully (Q2), classes related to engineering management, simulation, productivity, and statistics ranked highest in aggregate across all three semesters. Responses varied from semester to semester, which was most likely a function of distributing projects within the given semester. However, further analysis is needed to verify this assumption. Twenty-three classes were available for students to choose from. Figure 2 summarizes the courses that were most frequently selected across all semesters.

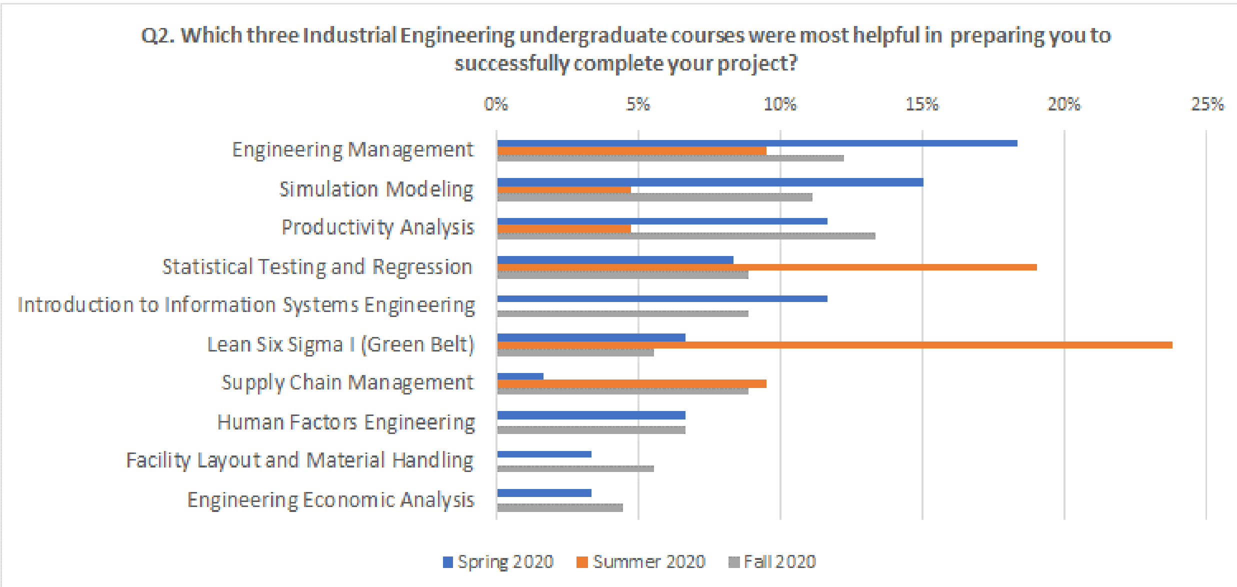

Figure 2. Top ten most frequently chosen courses in response to Q2.

Like Q2, Q3 and Q5, relate to ABET Criterion 5(d), which states the following:

> *The curriculum must include a culminating major engineering design experience that 1) incorporates appropriate engineering standards and multiple constraints, and 2) is based on the knowledge and skills acquired in earlier course work.*

Similarly, Q4 is specifically linked to ABET Criterion 3.1, that says:

> *…an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics*

Responses to Q3, Q4, and Q5 were captured in a multiple-choice format with respondents having the option of answering "Yes" or "No". Overall, most students within each semester agreed that 1) they had considered the use and application of appropriate engineering standards in their project (Q3), 2) their project could be classified as a complex engineering problem, and 3) they were required to work with realistic constraints. There was not a significant difference when comparing responses across semesters (95% significance level). Figure 3 - Figure **5** include graphical summaries of the proportion of responses by semester. Table 5 - Table **7** list the results of the between-semester Fisher's Exact Tests.

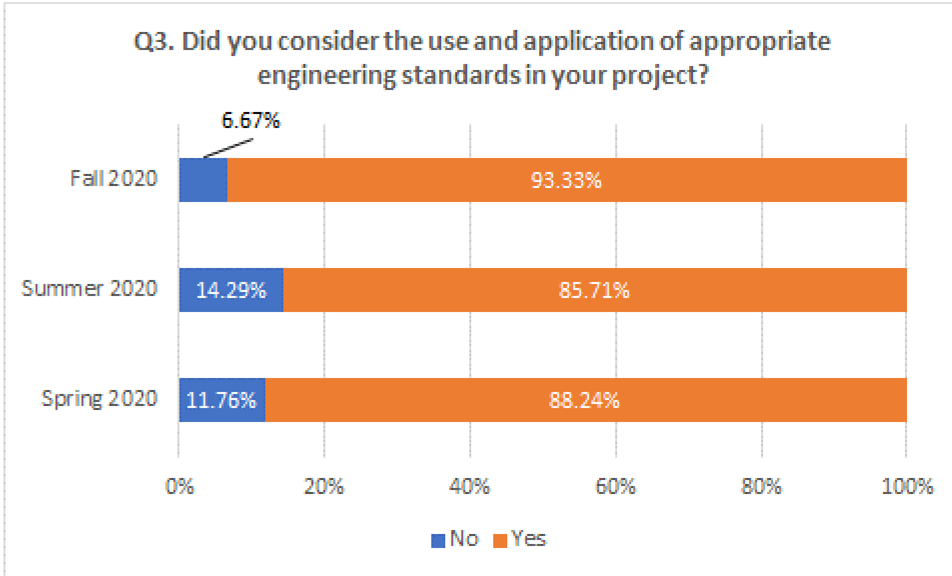

Figure 3. Summary of responses to Q3.

Table 5. Fisher's Exact Test p-values for Q3 (95% significance level).

Semester	Spring 2020	Summer 2020	Fall 2020
Spring 2020	--	--	--
Summer 2020	p = 1.000	--	--
Fall 2020	p = 0.613	p = 0.477	--

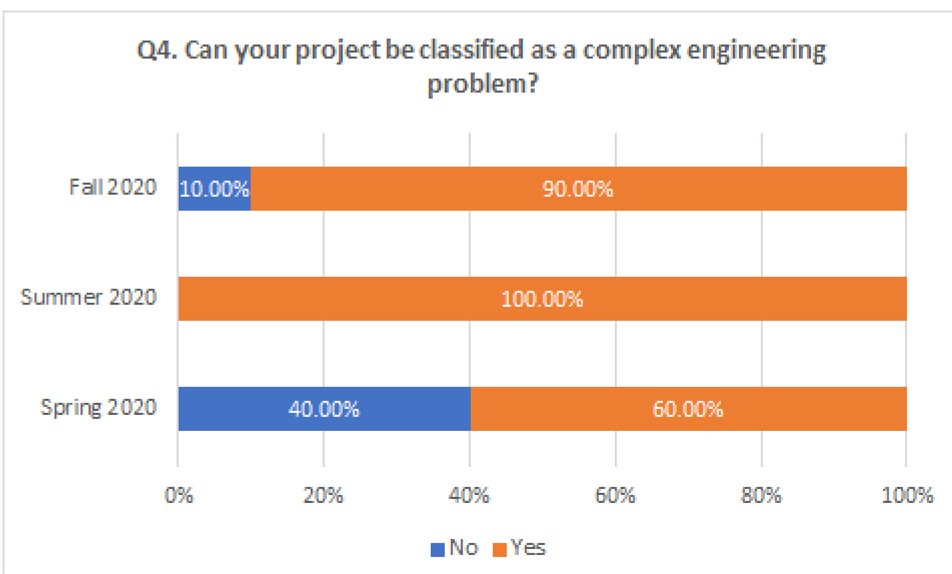

Figure 4. Summary of responses to Q4.

Table 6. Fisher's Exact Test p-values for Q4 (95% significance level).

Semester	Spring 2020	Summer 2020	Fall 2020
Spring 2020	--	--	--
Summer 2020	p = 0.068	--	--
Fall 2020	p = 0.017	p = 1.000	--

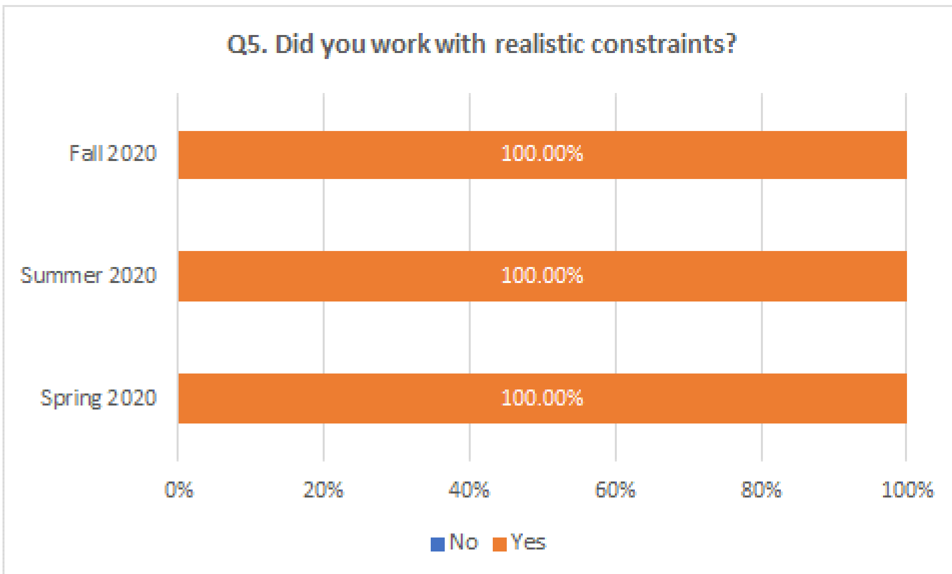

Figure 5. Summary of responses to Q5.

Table 7. Fisher's Exact Test p-values for Q5 (95% significance level).

Semester	Spring 2020	Summer 2020	Fall 2020
Spring 2020	--	--	--
Summer 2020	p = 1.000	--	--
Fall 2020	p = 1.000	p = 1.000	--

3.2 Learning Experience

The next set of questions (Q6-Q10) focused on the students' overall learning experience relative to the virtual learning environment (Q6 and Q10), working in a team (Q7), solving a real-life engineering problem, and relating to professionals in an engineering environment (Q9). For all semesters, most respondents indicated that the capstone course's virtual environment did not hinder their learning (see Figure 6). Similarly, when asked whether the remote environment created a hindrance in developing a solution to their team's problem (Q10), most respondents answered "No" (see Figure 7). The difference between the proportion of responses between-semesters was not found to be statistically significant (95% confidence level) for the two questions (Q9 and Q10) relating to the impact of the virtual environment on student learning (see Table 8 and Table 9).

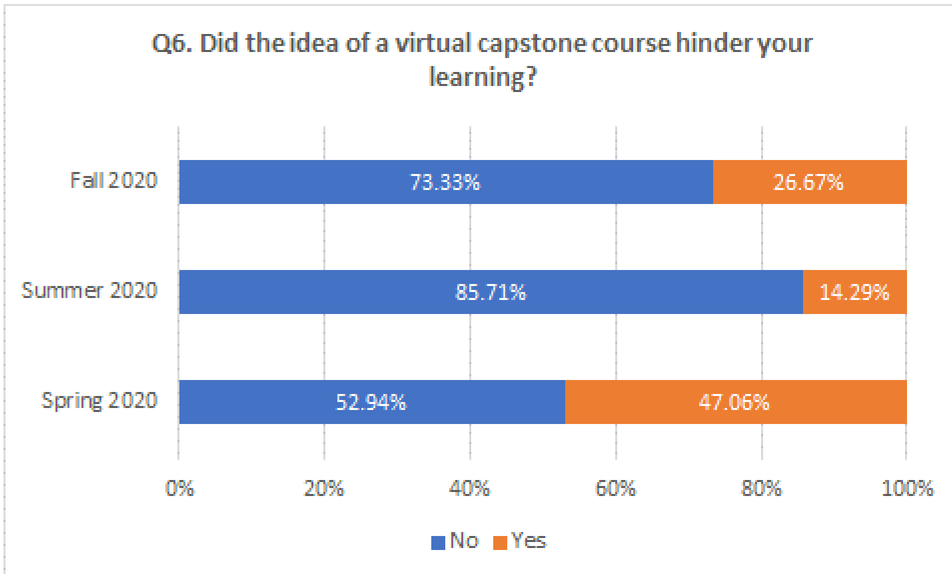

Figure 6. Summary of responses to Q6.

Table 8. Fisher's Exact Test p-values for Q6 (95% significance level).

Semester	Spring 2020	Summer 2020	Fall 2020
Spring 2020	--	--	--
Summer 2020	p = 0.191	--	--
Fall 2020	p = 0.206	p = 0.656	--

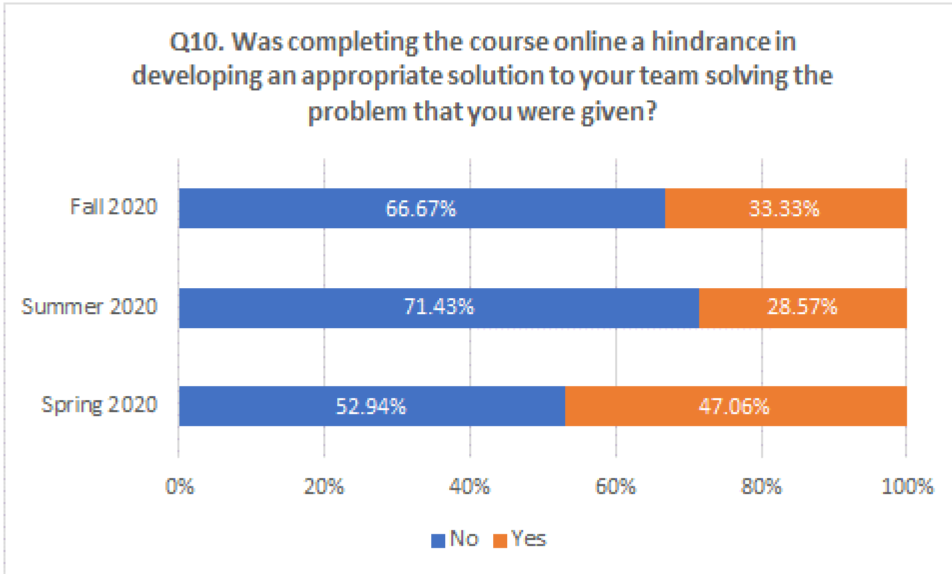

Figure 7. Summary of responses to Q10.

Table 9. Fisher's Exact Test p-values for Q10 (95% significance level).

Semester	**Spring 2020**	**Summer 2020**	**Fall 2020**
Spring 2020	--	--	--
Summer 2020	p = 0.653	--	--
Fall 2020	p = 0.371	p = 1.000	--

At least 50% of students in each semester responded that the course was extremely useful in learning how to work as a team (Q7, see Figure 8). For this and the remaining Likert scale questions, a slightly modified net promoter scale was used to assess student satisfaction from what was introduced previously (Equation 1). The formulation of the net promoter scale used for Q7, Q8, and Q9 is shown in Equation 2. The differences between net promoter scores from semester-to-semester were not statistically significant (see Table 10).

$$NPS_B = [\%EU + \%VU] - [\%MU + \%SU + \%NU] \qquad \textbf{Equation 2}$$

Where: NPS is Net Promoter Score
$\%EU$ is the percentage of respondents responding "Extremely Useful"
$\%VU$ is the percentage of respondents responding "Very Useful"
$\%MU$ is the percentage of respondents responding "Moderately Useful"
$\%SU$ is the percentage of respondents responding "Slightly Useful"
$\%NU$ is the percentage of respondents responding "Not Useful at All"

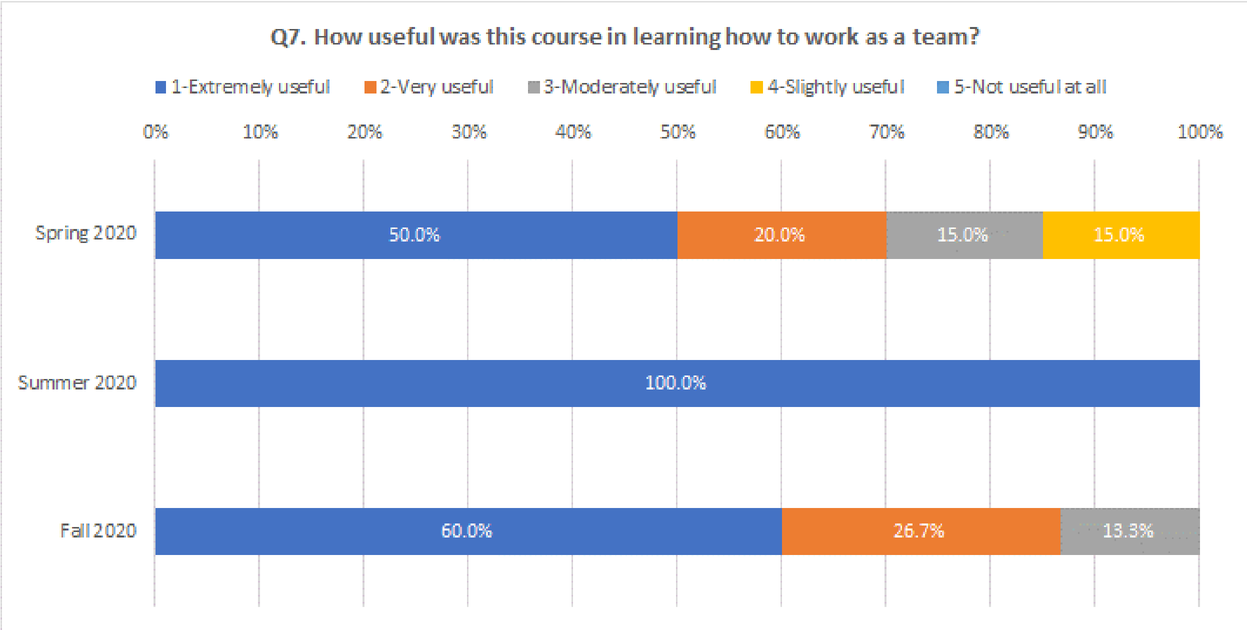

Figure 8. Summary of responses to Q7.

Table 10. Fisher's exact test p-values and net promoter scores for Q7 (95% significance level).

Semester	Spring 2020	Summer 2020	Fall 2020
Spring 2020	--	--	--
Summer 2020	p = 0.155	--	--
Fall 2020	p = 0.171	p = 0.570	--
Net Promoter Score (NPS_B)	40.0%	100.0%	73.3%

At least 50% of students felt that the Capstone Design course was either extremely useful or very useful in solving a real-life engineering problem (Q8) across all semesters (see Figure 9). However, Spring 2020 responses resulted in net promoter score of 0%, which indicates that the same proportion of students thought the course was extremely or very useful as those who felt the course was only moderately, slightly, or not useful at all in solving a real-life engineering problem. Further, the Fisher's Exact test results indicated that the net promoter score in the Spring 2020 semester was significantly different compared to the net promoter scores for responses to this question in both Summer 2020 and Fall 2020 (see Table 11). Although additional inspection is required, the distribution of projects relative to the distribution of student skills and interests may account for the differing results. Further, Spring 2020 was unique in the fact that the transition from face-to-face to remote learning occurred midway through the semester. Therefore, the newness of the changes caused by the COVID-19 pandemic may have played a role in the responses to this question. Interestingly, this was the only question had responses that resulted in statistically different net promoter scores when comparing one semester to another.

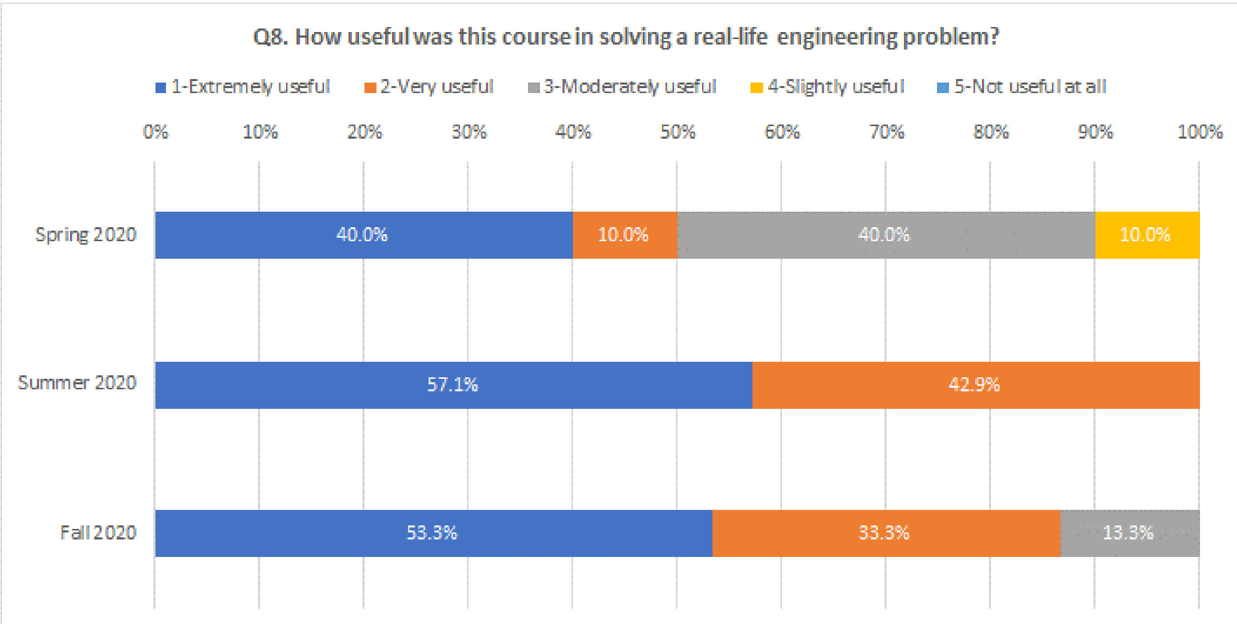

Figure 9. Summary of responses to Q8.

Table 11. Fisher's exact test p-values and net promoter scores for Q8 (95% significance level).

Semester	**Spring 2020**	**Summer 2020**	**Fall 2020**
Spring 2020	--	--	--
Summer 2020	p = 0.026	--	--
Fall 2020	p = 0.009	p = 0.570	--
Net Promoter Score (NPS_B)	0.00%	100.0%	73.3%

Question 9 (Q9) asked students how useful the course was in helping them deal with professionals in an engineering environment, 100% of respondents from Summer 2020, 43.3% of students responding from Fall 2020, and 30.0% of Spring 2020 respondents felt that the course was extremely useful in this regard (see Figure 10). In addition, a total of 10% of Spring 2020 respondents indicated that the course was either slightly useful or not useful at all when it came to Question 9. However, differences in net promoter scores between semesters were not found to be statistically significant (see Table 12).

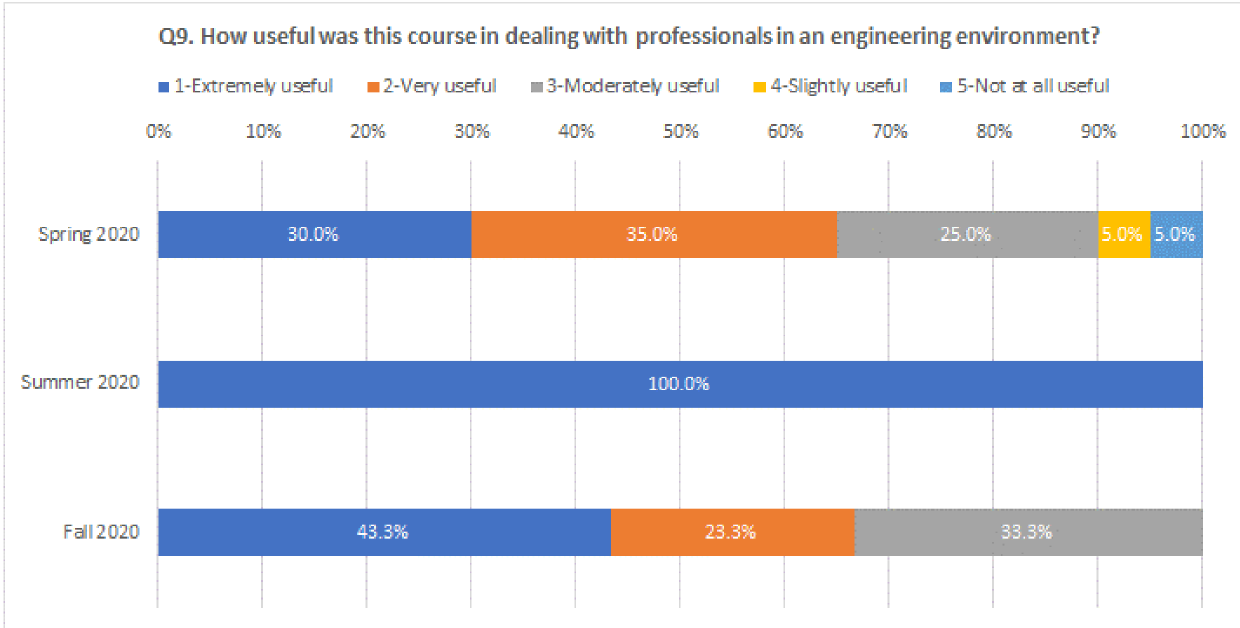

Figure 10. Summary of responses to Q9.

Table 12. Fisher's exact test p-values and net promoter scores for Q9 (95% significance level).

Semester	Spring 2020	Summer 2020	Fall 2020
Spring 2020	--	--	--
Summer 2020	p = 0.137	--	--
Fall 2020	p = 1.000	p = 0.155	--
Net Promoter Score (NPS_B)	30.0%	100.0%	33.3%

3.3 Student Preferences

To gain insight into student preferences, two open-ended questions were asked – 1) describe what you liked *most* about this course (Q11) and 2) describe what you liked *least* about this course (Q12). Word clouds (generated using wordclouds.com) were used to analyze the descriptive responses from these two questions for each of the three 2020 terms (see Figure 11 and Figure 12). Students consistently liked the work content, the problem they were tasked with solving, their team, their project, the real application, and working with clients. Relative to what they liked least about the project, students' responses most frequently included their project, the course overall, their team, and the level of difficulty and amount of work involved. Overall, it seems that much of what students enjoyed most, they also enjoyed the least.

Although speculative, it appears that individual student preferences and project availability may relate to their overall perception and experience in the course. For example, if a student has a high degree of interest in sustainability, but a sustainability project is not available during the semester, that student may have a less-than-favorable perception of the project to which they are assigned. In contrast, a student who prefers manufacturing and is assigned to a manufacturing-focused project may have a more favorable experience. Similarly, students' preconceived notions concerning the level of work required in the class may also play a role in the parity (or disparity) of their ultimate perception after completing the course. Further, other factors such as personality traits, skills, experiences, and behaviors may influence student preferences, expectations, and performance. Notably, individual student preferences may have been affected to a lesser or greater extent by the COVID-19 pandemic environment. A better understanding of the causes of these dichotomies is required. As a result, we recommend that the following additional work is completed (at a minimum):

- Modify Questions 11 and 12 of the survey to elicit more detailed responses and better understand what causes students to like and dislike the course elements.
- Conduct a comparative analysis of student expectations and preferences before and after completing the course.
- Continue the work contained herein once the COVID-19 pandemic is over to determine the effect that the COVID-19 pandemic had on student preferences.

Figure 11. Word cloud summaries for Q11.

Figure 11a. Spring 2020 | Figure 11b. Summer 2020 | Figure 11c. Fall 2020

Figure 12. Word cloud summaries for Q12.

Figure 12a. Spring 2020 | Figure 12b. Summer 2020 | Figure 12c. Fall 2020

4 Conclusions

The purpose of this research was to determine if the changes made to the Industrial Engineering Capstone Design course because of the COVID-19 pandemic had a significant effect on course requirements as well as the overall student experience. To gain better insight, a survey consisting of 12 questions was administered to students enrolled in the course during the Spring 2020, Summer 2020, and Fall 2020 semesters. Descriptive statistics and a nonparametric technique used to analyze discrete data, the Fisher Exact Test, were used to assess the results' magnitude and determine if two groups (pairs of semesters) differed in the proportional responses to the questions being asked. Except for one case, the differences in the responses between semesters were not statistically significant. Therefore, based on the questions asked and the corresponding answers, we can conclude that the changes made to the Industrial Engineering Capstone Design course at the University of Pittsburgh did not affect the ability to meet course requirements or the overall student experience within the timeframe studied.

In support of the conclusions above, this research provides some further insights. Namely, it is possible to successfully administer Industrial Engineering Capstone Design courses in a remote environment. Key factors to improve the probability of success include the following:

- **Project selection**. Select student projects conducive to a remote environment and associated with industry sponsors that can support remote activities.
- **Course structure**. Much of the learning associated with Capstone Design courses comes from their unstructured nature. However, additional structure and support are beneficial to the student experience in a remote environment. Examples include a detailed course schedule, supplemental lectures, team-building activities, and supplemental checklists.
- **Support**. Students will require additional support from their teammates, industry sponsors, faculty mentor, and course instructor in a remote environment. Diligently selecting and matching teams with a sound support system is critical.

5 Recommendations for Future Work

To enhance and extend the research described herein, the authors propose the following recommendations for future work.

1. **Comparative study**. The authors believe continuing this work in future semesters and including information and data from past semesters (prior to Spring 2020) would be of significant value. Doing so would provide an opportunity to further analyze the impact that COVID-19 has had on the Industrial Engineering Senior Design Capstone Course at the University of Pittsburgh.

2. **Incorporate additional data**. Although not included in this study, advanced insights can be gained by incorporating variables such as student preferences, demographic information, and other such factors into the research. Furthermore, developing additional dependent variables to assess outcomes in a manner different than what was presented herein would also be beneficial to the overall development, delivery, and improvement of online capstone courses.

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