Student and Faculty Perceptions of COVID-19's Impact on Engineering Preparedness

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Abstract

Many institutions required courses to be delivered in a hybrid or online-delivery mode in response to the COVID-19 pandemic. One challenge of the transition to a virtual learning environment is the impact on student learning outcomes for laboratory courses[1]. Education programs teaching labs in-person typically rely on hands-on experiments to prepare undergraduate students to develop and conduct appropriate experiments, collect and analyze data, work in teams, and develop statistical analysis skills - *engineering preparedness*. The transition to virtual instruction requires a change in the delivery of the lab content. The objective of this research is two-fold: (1) Assess the impact the sudden transition to virtual lab instruction had on engineering preparedness of students, and (2) Recommend laboratory course delivery strategies for institutions that will continue to require virtual instruction. This is achieved through a quantitative and qualitative analysis of self-reported perceptions of engineering preparedness of students, and a qualitative discussion from the instructors' perspective.

Keywords

COVID, pandemic, laboratory, virtual, online

Introduction

There are a wide range of problems where the best approach to obtaining a solution is through laboratory or field experiments, and there is much that can be learned from experimentation. The ability to design and conduct experiments, as well as analyze and interpret data, are important skills engineering students should learn as tools toward solving problems[2]. These skills can be learned in laboratory courses that require students to complete hands-on experiments, and student performance in these courses can be used as one measure of preparedness to solve engineering problems and communicate the findings[1]. For the purpose of this research, students' ability to develop and conduct appropriate experiments, collect and report data, perform statistical analysis, and work in teams, is referred to as *engineering preparedness.*

The research is conducted at two public engineering programs in the Southeastern United States: one is a Primarily Undergraduate Institution (PUI) where full-time faculty deliver lab instruction, and the other is a Research-intensive University (RU) where graduate laboratory assistants deliver lab instruction. The broader impact of the research is to improve the engineering preparedness of students in situations where virtual lab instruction may be required on short notice and to empower instructors with specific recommendations toward managing finite resources and planning for non-traditional lab delivery.

Traditionally skills learned in laboratory courses are acquired by hands-on experimentation in the physical presence of a laboratory instructor, but there has been exploration of alternative approaches to this learning paradigm[3]. In Spring 2019, a pandemic, COVID-19, began to spread across the United States which infected other parts of the globe at earlier and later times. A common reaction by educational institutions was to shift all instruction to an online delivery mode midsemester, including laboratory courses. This requirement to teach laboratory courses online on short notice created new challenges to achieving student learning outcomes in the absence of the physical equipment on campus. In-person restrictions continue to persist as the effects of COVID-19 linger which necessitates a thoughtful approach to virtual education.

The purpose of this research is to identify the impact the transition to virtual lab instruction has had on perceptions of the engineering preparedness of students, and to recommend laboratory course delivery strategies for institutions that will continue to require some form of limited in-person instruction. While virtual lab instruction is not new, the forced transition on short notice creates specific challenges that we look to address through a retrospective analysis of the academic term(s) conducted amidst the pandemic, a qualitative analysis of self-reported perceptions of engineering preparedness of students, and a qualitative discussion from instructors' perspective.

Literature on Remote Laboratory Education

From the perspective of Mechanical Engineering, the transition from in-person to online has led to the emergence of a few popular strategies to conduct virtual lab sessions. Some of these are: 1) Recorded videos, where students watch pre-recorded instructor videos of the experiments, and 2) Lab kits, where students use desktop kits to perform experiments remotely, and 3) Virtual reality, where students use virtual gamified lab experiences to replace in-person experiences. This section will highlight findings from previous investigations and present research opportunities.

Recorded Videos:
Researchers recognize that only watching lab experiment videos is limited in developing critical thinking and hands-on skills, because it does not fully emulate in-person lab experiences. Further work is required to identify lab modules suitable for this mode of delivery[1]. This mode also prevents students from experiencing the pitfalls of a failed experiment, and does not afford them the opportunity to experiment based on free inquiry[4]. Prior to the pandemic, some instructors prepared pre-laboratory videos to increase student preparedness for time limited hands-on experimental activities[5].

Lab Kits:
Investigators found that students are less likely to learn and apply advanced concepts, when using only lab kits[6]. This can be attributed to the lack of availability of industrial, standard lab equipment and reduced interactions with the lab instructors. This unavailability of standard lab equipment also leads to students delegitimizing their experience[6]. These findings suggest that the lab kit approach delivers the hands-on component of the lab experience, but does not enable students to experience real-world scenarios found in a conventional lab setting.

Virtual Reality:
Virtual labs are advantageous due to their availability at any time the students desire[7] and allow

students to gain technical knowledge associated with specific topics. Additional benefits of virtual labs include the ease with which data can be collected, the ability to perform/watch experiments without physical co-location, and the ability to operate independently[8]. However, virtual/remote labs without social interaction prevent students from developing interpersonal skills [7]. In addition, development of students' hands-on abilities is hindered in remote labs especially due to the lack of true haptic feedback and instructor supervision. This supervision ensures that students receive positive reinforcement and assurance when they perform experiments correctly, and also ensures that guidance is provided to those students who feel lost. Consequently, students may prefer remote lab instruction to occur later in the curriculum[8].

General Findings & Research Opportunities:
The current body of knowledge related to COVID-19's effect on engineering instruction is rapidly expanding. Despite this, minimal investigations are available on switching laboratory instruction mode on short notice. Many of the reviewed works were performed outside of the COVID-19 context, yet there is an opportunity to apply the learnings from these works to design future lab courses. For example, students in remote laboratory experiences significantly benefited from consistent, synchronous virtual contact with the instructor[8]. In addition to learnings from literature, this research uses the authors' experiences and student-reported data to provide recommendations for a spectrum of educational institutions.

Table 1 shows the various aspects of engineering preparedness that can be achieved through different lab delivery modes. There are opportunities to improve the delivery of labs by developing methods of including teamwork, conducting experiments, and reporting data.

		Lab Delivery Mode		
		Asynchronous videos	Lab Kits	Virtual Reality
Laboratory Engineering Preparednes	Conduct Experiments, Hands-on		Y	
	Collect and Report Data		Y	Y
	Perform Statistical Analysis	Y	Y	Y
	Collaborate in Teams			Y

Table 1. Engineering laboratory preparedness criteria for remote laboratory instruction

Methods

This research involves two public institutions in the state of South Carolina, specifically, the Department of Physics and Engineering at Francis Marion University, and the Department of Mechanical Engineering at Clemson University. Francis Marion University (FMU) is a primarily undergraduate, comprehensive teaching, public university with an enrollment of less than 5,000, and Clemson University (CU) is a research-intensive, public university with over 20,000 undergraduate students and 5,000 graduate students.

To evaluate the impact of the required transition to online/hybrid delivery method for traditionally in-person laboratory courses, this research considered instructor actions and changes to courses, student perceptions indicated on student surveys, and instructor feedback on student performance. The specific laboratory courses assessed at FMU are an Engineering Graphics course, a junior level Manufacturing Process Lab and a Technical Physics I Lab taught once a year by full-time faculty members with enrollment less than 20 students each. The laboratory class at CU is senior level mechanical engineering laboratory course taught every semester with enrollment averaging 120 students across 8 sections each semester, where graduate students provide the direct instruction of most students.

In March 2020, both institutions were mid-way into the academic semester, when mandates were issued to instructors to shift all instruction to online, including laboratory courses. This impacted the instruction of the engineering graphics course taught in a computer lab setting at FMU and the senior level mechanical engineering laboratory course at CU. Instructor changes to delivery mode for the Spring 2020 online mandate are described for each course.

Switch to online instruction midsemester Spring 2020:
FMU: In response to the computer lab shutdown, the engineering graphics course switched to an on-line, asynchronous instructional mode. Students did not necessarily have access to the Computer Aided Drawing (CAD) software used in the lab, so the instructor shifted instruction to emphasize the engineering design process using[9] on Perusall[10], an e-reader platform that allows students and faculty to annotate assigned readings. A new series of deliverables was created to teach fundamentals of problem definition, conceptual design, and detailed design, where students learned AutoCAD ® (which worked on their personal computers) to visualize and specify their designs. Advanced CAD topics, such as assemblies, machine drawings, bill of materials, and tolerances were substantially reduced, but because of the structure of the program and institution, it is anticipated these concepts can be integrated downstream into the curriculum.

CU: The instructor had approximately 1 week over Spring Break to prepare for an anticipated announcement regarding possible online education. A heat transfer, and a material fatigue failure lab module went fully online, via synchronous Zoom video conferencing with Graduate Laboratory Assistants (GLAs) continuing to provide guidance on reports and activities for all students. The GLAs conducted experiments, collected data, recorded videos of the procedures, and voice over slideshow presentations were created while lab access was still permitted.

Fall 2020 instruction paradigm and preparation:
FMU: This research focuses on two lab courses which were impacted: an introduction to Physics lab with 16 students, and a manufacturing lab with 9 students enrolled. Lab capacity was limited to maintain physical distancing protocols required by the institution, and room capacity was less than the enrollment, so traditional instruction was modified to a hybrid model for both courses. In the Physics lab, half the students in the class alternated between an online module, and an in-person module. Instructors recorded video of all laboratory experiment processes to show to online learners that week. All reports and forms were submitted online. To increase student engagement and improve clarity, multiple camera views were included in video overlays along with still images to show specific phenomena. All of this required increased file storage capabilities of the learning management system. The time spent in lab by each student was reduced in half to accommodate physical distancing requirements, and a new design project was included that could be completed remotely in the event another mandate forced labs online.

CU: The same senior laboratory course in mechanical engineering was offered in 8 sections of 16 students each, and the CNC Milling Machine lab module was replaced with a vibrations module emphasizing online activities. Room capacity of the laboratory is set to 4 students + 1 TA at a time with regular cleaning and hygiene policies in place for students and instructors, so lab time for each student was reduced to ¼ of the traditional 6 hours /week. Video content for all 5 modules in the course was created by a Lab Coordinator and team of GLAs in the event online instruction would be required, but also to support 1 online-only section of the course to accommodate students requesting to study remotely and complete all classes online. The summer 2020 period was active in the preparation of these videos and collection of representative experimental data to share with students who elected online learning only.

Assessment tools (surveys):
The laboratory courses cover topics related to required lecture courses in the curriculum and are designed to meet ABET Student Outcome(s) (ABET-SO): ABET-SO 3. an ability to communicate effectively with a range of audiences, ABET-SO 5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives, and ABET-SO 6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions. Students in the lab courses are required to write reports for several modules (SO 3), and work in teams (SO 5) to address engineering, science and technology problems using laboratory equipment (SO 6).

To evaluate student perceptions of the effectiveness of instruction and to evaluate their progress as developing engineers, laboratory course instructors collected student feedback on regularly administered surveys. Surveys after each module (Table 2.a) are used to collect formative feedback throughout the semester, and end-of-semester surveys (Table 2.b) provide summative feedback regarding the course overall. There is a mix of 11 Likert scale questions regarding their perceived improvement in specific outcomes for each module, and 3 short answer qualitative responses, to open-ended questions for students to comment on any aspect of the course. The end-of-semester survey contains eight Likert questions regarding overall coverage of material and perception of learning related to course objectives and ABET-SOs. The standard set of surveys has been deployed at CU for several years, so the impact of COVID-19 policies can be compared to previous semesters since Fall 2017.

Primarily Undergraduate Institution Results

Switch to online instruction mid semester Spring 2020:
The transition to online instruction in the latter half of Spring 2020 created new challenges for students to apply advanced CAD concepts (assembly modeling, converting 3D to 2D, and reverse engineering a product). However, students appreciated the opportunity to design a product from scratch, mirroring design processes from industry, and executing the design up to the detailed design stage. This was motivated by the e-readings assigned to them, which were focused on industrial applications of the engineering design process from multiple well-known companies (such as Lego, Microsoft, and Virgin Atlantic Airways). The e-reading platform, Perusall ©, was well-received by students. They engaged in online discussions with each other and with the instructor through the various features available on the platform.

Lab experiences in Fall 2020:
FMU Intro Physics Lab: Given the hybrid, unprecedented structure of this lab, instructors communicated logistics and expectations to students early and often thereafter. All students adjusted well to the hybrid mode of delivery, understanding that this is pandemic-induced and

not a long-term course of action. Some students expressed that they felt like they were "just watching YouTube videos", and began requesting for demonstration of experiments in-person. This request was easily accommodated since students attended in-person labs on alternate weeks.

a) Formative Survey Tool available to students after each laboratory module

1. Which lab was this?	[Short Answer]
2. The instructor clearly explained what is expected of students.	[Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree]
3. The instructor presented the laboratory materials clearly.	[Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree]
4. Relative to my other courses, the work load for this particular laboratory experiment was…	[Much Lighter, Lighter, About the Same, Heavier, Much Heavier]
5. Relative to my other courses, the difficulty level of the particular laboratory materials was…	[Much Lighter, Lighter, About the Same, Heavier, Much Heavier]
6. This laboratory enhanced or exemplified a subject that was only discussed in other classes.	[Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree]
7. This laboratory enhanced my understanding of engineering theory and/or practice.	[Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree]
8. My report writing skills and ability to discuss results and draw conclusions have been improved.	[Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree]
9. My software skills for modeling, simulation and data analysis have been improved by this laboratory.	[Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree]
10. I have increased my knowledge of statistics with engineering applications.	[Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree]
11. I have increased knowledge and experience in designing and conducting experiments.	[Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree]
12. The best thing about this class is…	[Short Answer]
13. My biggest complaint about this class is…	[Short Answer]
14. Other comments/suggestions?	[Short Answer]

b) Summative Survey Tool available to students at the end of the semester

1. Regarding report writing: Writing effective reports concerning experimental procedures and results.	[Minimal Coverage, Moderate Coverage, Extensive Coverage]
2. Regarding report writing: "My report writing skills and ability to discuss results and draw conclusions have been improved."	[Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree]
3. Regarding software: Use of software to acquire, analyze, and present data.	[Minimal Coverage, Moderate Coverage, Extensive Coverage]
4. Regarding software: "My skills in the use of software for data analysis, plotting and presentation have been improved by experiences in this course."	[Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree]
5. Regarding statistics: Application of statistics in the analysis of engineering data.	[Minimal Coverage, Moderate Coverage, Extensive Coverage]
6. Regarding statistics: "I have increased my knowledge of statistics with engineering applications including uncertainty analysis."	[Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree]
7. Regarding design of experiments: Design of test procedures, selection of instruments, randomization, and calibration.	[Minimal Coverage, Moderate Coverage, Extensive Coverage]
8. Regarding design of experiments: "I have increased my knowledge and experience in designing and conducting experiments."	[Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree]

Table 2. Survey tools used to assess student perceptions of laboratory experience

In terms of achieving course objectives, one objective relates to students writing weekly lab reports, which was reduced and substituted with weekly online-form submission. However, two formal lab reports were required of the students. These formal reports allowed the instructor to provide feedback on writing style, formatting, and presentation of numerical results. A second course objective is related to students' ability to collect and analyze data. Since both groups of students performed in-person experiments, they both gained experience collecting and analyzing data on computers. This objective was achieved because of the hybrid mode of delivery.

FMU Manufacturing Lab: In general, there were fewer concerns in this lab course. This could have been due to the fact that the students in the course were at least juniors, who are more accustomed to university ways (such as regularly checking emails, approaching faculty outside of class hours, and getting help from classmates.) The format of this lab course gave students ninety minutes of idle time every week. The proportion of students who actively used these idle ninety minutes, increased as the semester progressed. This is attributed to constant reminders from the instructor and feedback gained from graded assignments.

One course objective is related to students' ability to recognize and follow safety protocols. Students were lectured on, and reminded of safety protocols several times at the start of the semester. Towards the latter half, students began following protocols on their own.

Another course objective relates to the students' ability to design manufacturable products. The lab project allowed students to apply their knowledge of engineering design, engineering graphics, material science, and manufacturing processes to design and build a product. The last course objective relates to students' ability to gather and analyze data critically. While not required as formal lab reports, students were required to gather, interpret and analyze data from various materials and manufacturing experiments. This would have been hard to achieve if an online-only mode of delivery were used.

Research University Results

Switch to online instruction mid semester Spring 2020:
The answers to Likert scale questions were assigned point values on a linear scale [-2 strongly disagree, -1 disagree, 0-neutral, +1 agree, and +2 strongly agree]. The average value for each semester is presented in chronological order, from Fall 2017 through Fall 2020, for each of the survey questions beginning with the Heat Transfer module (Figure 1). To observe the impact of COVID-19, results are shown for question 3 for instructor Presentation, questions 4 & 5 for Workload and Difficulty, and questions 7-11 on learning content: Theory, Writing, Software, Statistics, Experiments. The horizontal bar for each question indicates the average of the semester averages prior to COVID-19 impact. The goal of this data analysis is to identify specific parameters that may be attributed to COVID-19 policies, and averages that are outside the 99% Confidence Interval (~2 standard deviations for this data set) for all semesters prior to COVID-19 are considered statistically significant parameters.

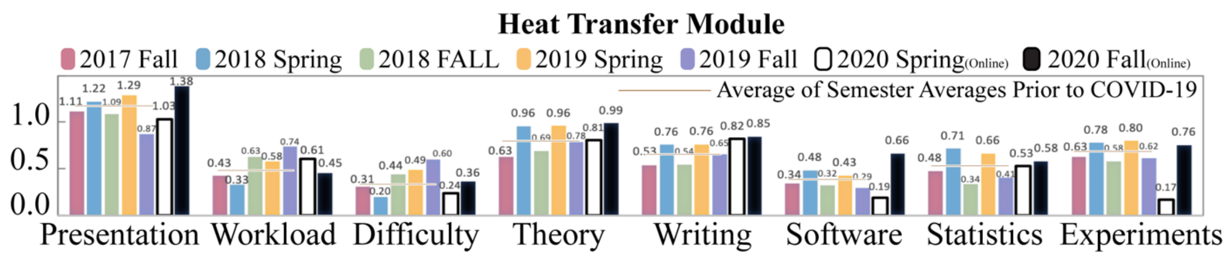

Figure 1. Heat Transfer Module Survey Results at Clemson University

In Spring 2020, the first lab module to be taught fully online was the Heat Transfer experiment, where students investigate forced convection. GLAs who instruct the individual sections helped prepare videos and content over spring break. Students were required to virtually attend weekly synchronous lab periods to meet with their team and engage with the GLA.

Heat Transfer module survey results from students indicate they perceived their increase in knowledge and experience in designing and conducting experiments to be notably less than students in previous semesters (Figure 1). They also indicated higher improvement in Writing and that they learned less regarding Software. One explanation could be that they didn't have to spend two days in lab conducting experiments, as the experiments were video recorded in advance by the instructors and students were handed the resulting data set, so they also had more time to analyze data and write reports. Student comments on the qualitative questions indicate a theme of, favored learning in teams, reinforcing content from lecture course, strong instruction by GLAs, and preferences to conduct experiments and collect data in person.

The next, and last module, of that Spring 2020 semester was the Fatigue experiment, where students investigate the fatigue failure of metals in alternating bending stress. Similar to the Heat Transfer experiment all content was transferred to an online environment. Fatigue failure module survey results from students indicate they perceived their increase in both learning outcomes of Writing and Statistics to be higher than students in previous semesters (Figure 2). Student comments on the qualitative questions indicate a theme of, preferences for the executive summary and slideshow format over full reports for other modules, favored teamwork, strong instruction by GLAs, application of concepts learned in lecture courses, preferences to conduct experiments in person, and some confusion on assignment expectations.

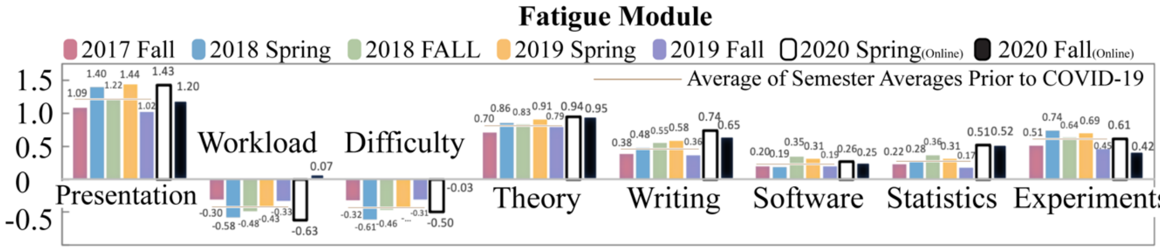

Figure 2. Fatigue Module Survey Results at Clemson University

CU Lab experiences in Fall 2020:
The Fatigue module was the first experiment in Fall 2020, and all content was delivered exclusively online. The survey results indicate students perceived their increase in Statistics to be higher than students in previous semesters (Figure 2), similar to the Spring 2020. Students indicated an increase in the Workload and Difficulty, despite no changes to the deliverables from previous semesters. One explanation could be the adjustment to starting the semester remotely and all online for all of their classes, but student comments on the qualitative questions indicate themes of confusion on deliverables requested, and undesirable formatting and presentation of the data that was provided to students. Based on submissions and qualitative survey data, the instructor indicated the students may not grasp the complexity of fatigue failure concepts.

The Mass Pendulum module was delivered in a hybrid instructional mode, where teams meet virtually amongst themselves and with GLAs. In this module, students model and validate experiments of a pendulum attached to a translating mass that is attached to a spring. Time in lab was required but was reduced from the traditional 18 hours to 1.5 hours per person/ week, so all students had the opportunity to conduct limited experiments. Survey results indicate they perceived their increase in Writing to be higher than students in previous semesters (Figure 3). Student comments on the qualitative questions indicate themes of, appreciation for conducting experiments in person, learning modeling software, desire to exceed the maximum report page limit, and practical challenges of hybrid lab delivery.

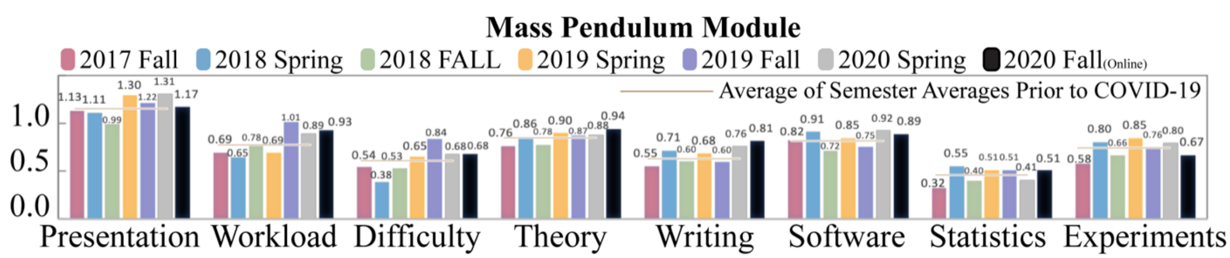

Figure 3. Mass Pendulum Module Survey Results at Clemson University

The Programmable Logic Controller (PLC) module, delivered in hybrid mode, emphasizes the integration of physical sensors with ladder logic programming to create a building security system. Survey results indicate they perceived their increase in Experiments to be less than students in previous semesters (Figure 4). Student comments on the qualitative questions indicate themes of, valuing hands-on experience in lab, valuing open-ended nature of the lab module, challenges with the online PLC emulator, insufficient in-lab time to complete experiments, and challenges of limiting lab access to one person per team at a time.

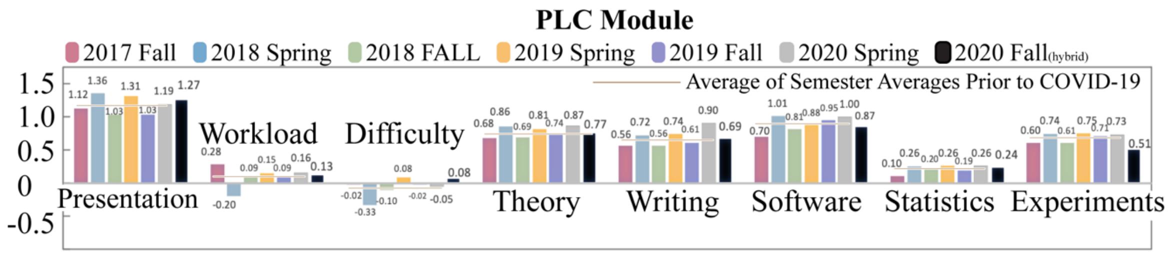

Figure 4. PLC Module Survey Results at Clemson University

At the conclusion of the semester students reported learning in all the assessed areas, and the End-of-Semester Survey indicates that students in Spring 2020 and Fall 2020 perceived their increase in Statistics to be greater than students in previous semesters (Figure 5).

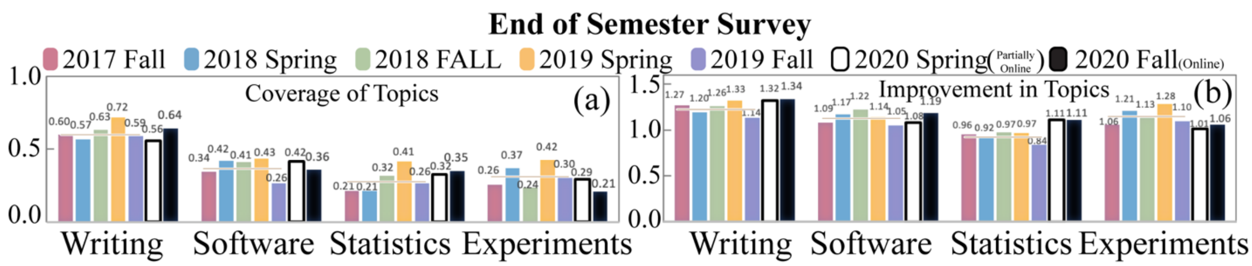

Figure 5. End-of-Semester Survey Responses at Clemson University

In summary, more students disagreed that they increased their knowledge of conducting and designing experiments in the online/hybrid instruction than students in previously traditional sections, and online/hybrid instruction was perceived to be more difficult in the fatigue module. However, results from surveys to online/hybrid modules indicate they more strongly agree to be improving their writing skills and applying statistics than students of past semesters with traditional instruction. One possible explanation for these results could be that students measure their perceived learning by the time (or cognitive load) they spend on task, so as experimentation was moved online and reduced in time to shorter, streamlined, digital formats, students were spending less time learning about experimentation and more time dedicated to writing and statistics. Alternatively, students may be less prepared to write and apply statistics without conducting experiments, so they had to learn more during the writing and data analysis process.

Recommendations

Online and hybrid laboratory instruction may be necessary on short notice in response to a pandemic, severe weather events, power outages, etcetera. Stable electrical power, computing capabilities, and reliable internet access, are vital to continue instruction remotely. Safe in-person instruction in engineering laboratories requires instructors, modern tools, floor space, furniture, and custodial services, so there are some advantages to moving all or some portion of laboratory instruction online. One challenge with completely online and virtual laboratory instruction is that students may be less prepared for true experimentation requiring hands-on skills, or addressing situations where equipment systems do not function together as anticipated, so it recommended that some hands-on component be integrated into laboratory instruction.

Despite the challenges, students continued to meet learning outcomes overall in the laboratories, regardless of in-person experimentation, but both institutions supplemented asynchronous on-line content with regular synchronous, on-line meetings with instructors. The instructors continued to answer questions on theory, demonstrate physical principles, show examples of experiments to engage students, and they also held them accountable for activities in the synchronous virtual sessions. Specific feedback can be provided to targeted individuals instantly using the professional judgement of an instructor to keep students focused on the learning objectives. Synchronous sessions also allow students to benefit from their peers. An alternative that was also used was online discussion, specifically the e-reader, Perusall ©. Such platforms allow for students to participate in discussions on instructor-posted text documents and/or videos, and has shown to engage otherwise reserved students.

Improving teamwork skills is an ABET SO for laboratory courses at both institutions and should be considered in assessment. During the transition to online instruction, instructors were focused on moving laboratory content online, with less emphasis assessment of teamwork in a virtual environment. It is recommended to incorporate teamwork skills and develop related assessment strategies, that lend themselves to both traditional instruction as well as online education.

One advantage of educational programs where students progress as a single cohort with small class sizes, is the ability to readily track students. Any topics or hands-on experiences that may have been omitted could be addressed in specific subsequent courses to make sure the students meet learning outcomes before graduation. Coordinating the adjustment at larger institutions with multiple sections of classes offered every semester is more difficult. Either way, it is recommended to conduct formative assessment and leverage resources to make adjustments before the semester ends.

Conclusions and Future Work

Educational institutions closed classrooms and laboratories in response to COVID-19, and access in many instances is still limited but increasing. Hands-on experience is essential to preparedness in fields such as mechanical engineering, but laboratory kits take time to develop and require additional costs, so maximizing usage of existing laboratory resources will be an asset to achieving student outcomes. Regular, synchronous interaction with instructors allows for timely feedback to students to address individual learners; alternatively, asynchronous lab content can be developed, but it requires advance planning. Instructors may have to accommodate online-only learners due to quarantine or individual circumstances preventing attendance on campus, and future work would be to research the impact of having a subset of the students in a traditional or hybrid course choosing to complete the same laboratory courses online concurrently with traditional/hybrid instruction of students. Certainly, the response of academic institutions during the COVID-19 pandemic will shape educational delivery methods in the future when health concerns have been restored to earlier levels with campus learning spaces fully operational.

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