Approaches to Teaching a Biomaterials Laboratory Course Online

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***Abstract*—The COVID-19 pandemic has changed the landscape of the employment, health care and educational systems throughout the world. Approximately 5,300 universities in the United States had to rapidly transition to the online teaching platform. Although online teaching has been around since the 1990's many undergraduate engineering programs have resisted their full adoption due to high attrition rates, difficulty in the instruction of mathematically intensive courses and the lack of hands-on experiential learning necessary for ABET accreditation. In this study, we address challenges faced by incorporating a biomaterials laboratory course online. First, we assessed student satisfaction and learning outcome of a hands-on biomaterials laboratory module replaced by a virtual lab simulation. Course surveys and quizzes were used to determine student satisfaction, learning outcomes and confidence level. In the second investigation, we evaluate the course learning outcome that measures the ability to conduct experimentation and draw conclusions. Results have shown that the virtual laboratory achieved satisfactory learning outcomes and was preferred by most of the students that were surveyed. In the case of a pandemic or any emergency situation, online teaching pedagogy is essential for students to remain engaged and learning outcomes to be achieved. Furthermore, success with these techniques can be used as a catalyst for the adoption of future online programs that can open the door to job opportunities for multiple student populations.**

***Index Terms*— biomaterials, virtual lab, online laboratory**

Introduction

The COVID-19 pandemic turned the global economy, health care system, education, and societal norms upside down. As society turned to the online platform future considerations of how business will be conducted has become questionable. The pandemic may cause companies to re-think telecommuting employment and the department of education may integrate more online programs to address the needs of various student population. Some businesses may never fully recover, therefore leaving the job market with a need to retrain a portion of the workforce. The pandemic has shown the greater need for a robust health care system as well as the need to embrace the online educational platform.

As schools, colleges, and universities across the globe were forced to teach through the online environment to practice social distancing and minimize viral spread, every educator had to quickly adopt online practices. Prior to these events, distance learning has been in the higher educational system since the 1990's. Integrating more online courses and programs can have added benefits. First, online education can increase the number of qualified workers in the labor pool and produce a variety of skill sets in the market [1, 2]. This may yield greater innovations and opportunities for populations that would not otherwise be able to enter technical fields. Next, institutions may reduce some of the overhead costs needed to run labs, classrooms, and office spaces. Online programs have the potential of allowing more students in a classroom without the logistical planning of being on campus [2].

Although distance learning has been present in higher education for a long time, some disciplines have not fully accepted the online teaching model. Despite the many advantages of online learning, challenges still exist in the online teaching world. Such drawbacks include the high attrition rates due to time management, workload, level of difficulty, and lack of student engagement [1, 3-5]. Other factors may be due to the curriculum and accreditation process. Undergraduate engineering disciplines have been slow to adopt the online pedagogy.

Since engineering programs need to demonstrate specific learning outcomes for accreditation, online adoption has been stagnant [2, 5]. Engineering programs must demonstrate ABET student outcomes that have been challenging in the virtual model. With the need to demonstrate outcomes such as: "the ability to solve complex engineering problems…" and "the ability to conduct experiments…", the development of the online platform has not been a priority. Most engineering courses are mathematically intensive and require derivation and equation manipulation. These types of courses can be difficult for the instructor to implement and the student to comprehend online [2]. Hands on laboratory experiments are another challenge that engineering programs face. Some programs that have online undergraduate engineering curriculums that are hybrid will still require students to take on campus laboratory courses [5, 6]. In the case where emergency online teaching is needed, some programs have provided instructional videos of experiments being performed with explanations of the equipment being used. The students are then given data to analyze from the experiment shown in the video. However, this approach is only successful when making videos that are interactive and engaging.

To address these hurdles, online engineering programs have implemented hands-on components through multiple avenues. Hands on kits, simulation software or virtual labs are being utilized [5, 6]. Furthermore, pedagogy and teaching strategies are imperative in the success of online curriculums. Studies have shown that successful online programs apply a series of student engagement strategies and allow students to feel a sense of community within the online classroom [7-9]. In addition, the Sloan Consortium defines quality online education by five pillars. According to this consortium, online learning can be effective if the following criterions are met: 1) learning effectiveness, 2) cost effectiveness, 3) access, 4) student satisfaction, and 5) faculty satisfaction [9]. Learning effectiveness occurs when a student has demonstrated both comprehension and application of new knowledge. In a laboratory course, this will be heavily dependent upon the knowledge obtained during the lecture component. Next, cost effectiveness ensures that both the technological requirements are not too expensive and can include savings for the universities in the form of labor costs, logistics, and classroom space. Ease of accessibility for online content is also necessary. Then, the technological infrastructure must be able to fully support the online learning environment, and student satisfaction is key to determining the success of an online program. Many studies have shown that students need to be engaged and be a part of the learning process [1,8,9]. Finally, faculty satisfaction, is a key for the entire online learning process to be effective. Each of these pillars also have many other components in a successful online program.

In this study, during the COVID-19 pandemic, the implementation of a biomaterials laboratory course online is discussed. Strategies used to improve the experiential learning of a laboratory class are discussed. The study assesses a virtual lab module and overall learning outcomes of the course. Strategies used to make the course more engaging are also discussed. By determining techniques that are successful, we hope to lay down the seeds for future online biomedical engineering programs.

A. Methods

The biomaterials laboratory course is delivered on-campus with a lecture course, both taken in the junior year of the undergraduate biomedical engineering program. This course is also used as an elective for the graduate program in Bioengineering. The course was designed to provide students with real life experience working with an implant material. To implement this objective, the course was developed to walk students through the engineering design process. Students are asked to complete eight modules in a sixteen-week semester long project. Students were introduced to a top athlete in the news and asked to repair their fractured femur by designing a bone tissue scaffold. This approach is used to connect students with a real-life problem that needs to be solved. The course learning outcomes were the following:

1. Discuss the step-by-step process of cell culturing.
2. Design and analyze an implant using Solidworks.
3. Design and conduct experiments and use the experimental data to draw conclusions in the development of an implanted design.

As shown in Table I, the lab modules needed online modifications in several weeks of the course. It is also important to note that since Solidworks was an essential part of the curriculum prior, minimal modifications needed to be made for those modules. In the on-campus setting the course is typically taught by first providing students with an introductory 10-minute lecture, and the rest of the three-hour lab period is spent performing the experiments for the lab module. In the online format the students watched interactive videos of the experiments, analyzed data, used software for design, and completed a virtual lab. Solidworks was used in previous semesters as part of the laboratory modules and did not demonstrate any significant changes in student outcomes which is also dependent on previous mastery and experience. For example, some students are more proficient in Solidworks due to co-ops, courses, or high school preparation.

TABLE I.
BIOMATERIALS LABORATORY MODULES

Module	Student Task	Online Teaching Modification
Module 1: The Need and Problem Formulation	Learn about fracture femurs and design specifications of bone scaffolds.	Zoom lecture
Module 2: Testing a Bovine Femur	A bovine femur sample is tested to provide students with baseline information.	Interactive video showing test procedure, Send data to students for analysis
Module 3: Brainstorming Ideas and Designing	Each team member designs a bone scaffold in Solidworks.	Zoom breakout rooms with teams; Solidworks
Module 4: Analysis of their Design	Each student performs a Finite Element Analysis on the design and selects the best performing design amongst their team.	Zoom and tutorial videos; Solidworks
Module 5: Manufacturing	Students select the 3D printing parameters and analyze their printed designs.	Interactive video, Send them pictures of their printed designs.
Module 6: Compression testing printed design	The selected design is compressed on the Instron and students analyze the data.	Interactive video showing test procedure, Send data to students for analysis
Module 7: Cell Culture and Viability Test	The scaffolds are tested using the Alamar Blue Viability test	Labster- Virtual Lab, Videos
Module 8: Design Pitch	Each group used the acquired data to convince the class why they feel their design worked the best.	Zoom

Participants

Twenty-five students were first trained and introduced to a cell culture virtual lab module. The course consisted of twenty-two undergraduate biomedical engineering students and three bioengineering graduate students.

Virtual Lab Assessment

One of the challenges faced during the pandemic was having students perform a hands-on experiment such as a cell culture lab. This module is key to developing cells that will be seeded onto their designed bone tissue scaffolds. Students were briefed on how to use the virtual lab (Labster, Thermofisher- Cell Culture Basics) in a Zoom laboratory lecture. Each student was given one week to complete the laboratory assignment. Following the completion of the virtual lab, they were asked to complete a survey that assessed their satisfaction and overall confidence performing an in-person cell culture laboratory module. To investigate the learning efficacy of the virtual lab, students were first asked to assess their ability to cell culture after completing the module. Next, they were quizzed on writing the steps that are required to complete a cell culture laboratory experiment. Each student was assessed consistent with the grading rubrics outlined in Table II.

TABLE II

Grading rubrics used for cell culture assessment.

Performance Criteria	**1- Poor**	**2- Satisfactory**	**3- Good**	**4- Exemplary**
Delivery	Poor spelling and grammar mistakes.	Minor spelling and grammatical mistakes.	Acceptable grammatical usage and delivery.	Excellent usage of sentences and structure.
Description of Process	Listed less than three steps of the cell culturing process.	Listed more steps involved in the cell culture process and discussed each minimally.	Acceptable listed steps involved in the cell culture process and a discussion of each step.	Exceptional detail to the steps involved in the cell culture process.

Course Learning Outcome Assessment

The course has the learning outcome to "Design and conduct experiments and use the experimental data to draw conclusions in the development of an implanted design". The outcome was assessed directly by their final design pitch. Students were graded in three categories: design, data analysis, and argument on a scale from 1- poor to 4-exemplary in each of these categories and the score is averaged together for a total score. To indirectly assess the students, the course survey results were used. This was compared to previous semester where the course was delivered on-campus.

B. Results

In this biomaterials laboratory, we have used several strategies to tackle the challenges of converting a hands on course to the online platform.

Real-world problem

First, the course modules were introduced with a real-world problem. This strategy is used to connect students with the course material throughout the semester. By providing students with the opportunity to see first-hand how a biomedical engineer solves a medical problem, they become more engaged and are involved in their learning process [14]. Students commented that they felt the lab was more interesting because they were working on one goal the entire semester.

Instructional Videos

Next, to convey and illustrate the experimentation process instructional videos were used. As outlined in Table I, many of the components of this lab required students to conduct an experiment and analyze results. For example, in Module 2, students were required to test a bovine femur on the Instron and describe the mechanical properties of their biological sample. In addition, they test their designs later in the semester using the same skill sets. Since students could not physically perform this task, they were given a Zoom lecture and watched an interactive video developed describing the process. The data was then sent to students to analyze. It is important to note that the videos should not be more than a few minutes and should be as interactive as possible (which were made through tools such as: Microsoft Video Editor) The instructor should stop the video and ask questions to ensure students are still engaged with the content. This is one technique that was used to replace some of the hands-on components and can be further enhanced in the future.

Breakout rooms

Putting students into breakout rooms was a critical part of the laboratory engagement process. Each team was put into a breakout room and asked to complete the lab module with their group. The instructor can then go in and connect with their students. In some cases, it was difficult when students had their cameras off. Nevertheless, asking them open-ended and thought-provoking questions helped students stay engaged.

Virtual Laboratory

Another technique that was used to replace the on-campus component was the Labster virtual lab software. To assess the virtual laboratory tool students were introduced to a videogame like virtual lab module. In the virtual lab the player or student is performing every step of the cell culture process (see Figure 1). Once the students completed the module, they were asked to rate their satisfaction. Student satisfaction with the virtual laboratory was measured based on a scale of 1 to 4 with (1- poor, 2- fair, 3- good, 4- excellent). Figure 2 demonstrates that the responses where favorable with 84% of the students being satisfied with the virtual laboratory module. Next, the student confidence level to perform the cell culturing tasks in the real-world were also assessed. Approximately 64% of the students participating in the survey felt they would perform good and 12% thought their performance would be excellent completing a cell culture hands on lab in person.

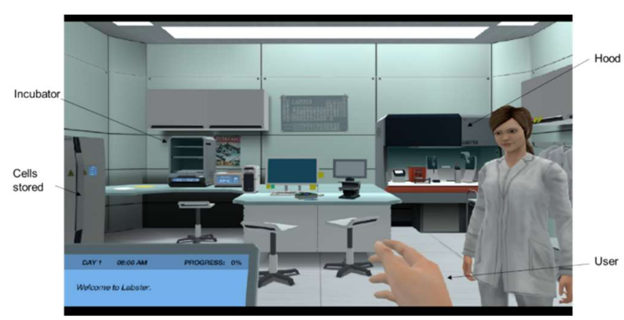

Figure 1. User interface upon entering the virtual lab. The user/student is guided on the cell culture techniques and performs each step.

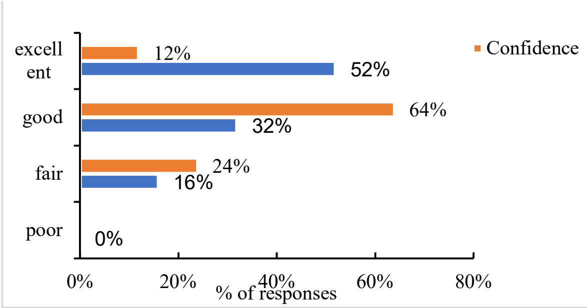

Figure 2. Student surveys measuring student satisfaction and confidence level to perform the cell culture tasks in a laboratory after completing the virtual lab. N= 25 students

To directly assess if the learning outcome of the cell culture module was achieved, students were given a quiz which asked them to write down the detailed steps involved in culturing cells to compare the self-assessment with their actual performance. The assessment found that students performed at approximately 2.8 out of a rating of 4.0 This is consistent with how students have performed in previous semesters where the course was taught on-campus.

<u>Design Pitch</u>

The learning objective of the biomaterials lab was to design and conduct experiments and use the experimental data to draw conclusions in the development of an implanted design. This course learning outcome directly maps to the ABET student outcome 6, "an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions", in the biomedical engineering program. Table III summarizes the results of the assessment. From the one semester of online instruction, it is evident that the students did not perform as well as they have in the past four semesters when the course was taught in person. This could have been to the adjustment to the new learning environment.

TABLE III

Summary of the course learning outcome direct and indirect assessments

Delivery Mode	Direct Assessment	Indirect Assessment
Online (Fall 2020)	2.90	3.24
On-Campus (four previous semesters averaged)	3.75 ± 0.1	3.62 ± 0.3

The design pitch assesses how well students were able to use the design specifications of a bone tissue scaffold to implement a design, analyze the data that was obtained through each module, and convince the audience of how well their design performed. This task is very challenging for students as they are often surprised by the results of their design. However, they were provided with tools on how to analyze the data and suggest alternative applications. The winning team got a 100% on their lowest quiz score. The students were very competitive in their design pitches and commented in course surveys that it made the course fun.

C. Discussion

With the emergency teaching necessary in the COVID-19 pandemic, instructors and institutes struggled to rapidly adapt to the online teaching platform. Experiential learning is one of the most significant methods used in any engineering curriculum and has been one of the hurdles slowing down the adoption of online undergraduate engineering programs. Hands-on laboratory skills are a primary source for learners to obtain skills necessary for the work force.

As universities begin to think about implementing online programs other tools can be utilized. Integrating virtual reality, simulation, or software programs can be beneficial tools to use for online teaching [5, 6]. Using virtual labs have many advantages for student learning and in some cases have shown to improve learning outcomes [11, 12]. Virtual lab simulations allow students to actively learn abstract topics that may be otherwise difficult to grasp and provide them with the ability to learn at their own pace. In addition, in situations where laboratory equipment is too expensive or lab space is limited, the virtual laboratory is an effective alternative [11].

Cell culturing is a module introduced in a biomaterials laboratory as a fundamental skill set necessary for cell viability testing on a designed implant. This module takes many days of preparation and students are required to demonstrate the ability to perform this task. Providing students with a tool to self-engage into the activity was favored by most students. One of the challenges that may arise with using software online is the technological disparities. Some students may not have computers that can support the software. However, since the virtual lab was used through a website this was not evident in this study.

Using engagement strategies such as introducing a real-world problem to solve, interactive instructional videos, using break out rooms, and tapping into their competitive spirit was found to be favorable and was noted in the student survey comments. Many students also made comments about their mental health, which was also noted amongst many universities throughout the country [15, 16]. It is imperative that instructors understand and become attuned to the impact of mental health in the classroom. Incorporating a Wellness day into the semester, having fewer rigid timelines, and empathizing with the socio-economic stresses placed on many students during times of difficulty is key to obtaining better learning outcomes.

D. Conclusions

Emergency situations are a part of human existence. Colleges and universities often run into emergency closure situations due to the weather, maintenance of facilities, or other unforeseen circumstances. We must be able to adapt to changes with the most effective resources and tools that we have available. Technology is advancing at a highly rapid rate and as educators we need to utilize and adopt these tools to effectively teach our students. Online learning has been around for a long time but has not been quickly welcomed in many disciplines due to high attrition rates and the challenges of providing students with experiential learning. Since engineering courses are mathematically intensive and require completion of laboratory courses, adoption of the online teaching paradigm has been minimal. In this study we have used techniques to improve the online pedagogy of a Biomaterials laboratory course during the COVID-19 pandemic. The door to online teaching and program development has now begun to open. Utilization of this platform can be quite advantageous if challenges are predetermined and mitigated.

ACKNOWLEDGMENT

I would like to thank Dr. Hongjun Wang for his input on the development of these lab modules.

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