

Teaching an Engineering Lab Through Hybrid Instruction

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Abstract

Currently, all over the world most of the courses are taught in traditional face-to-face method. In the developed countries, more than 50% undergraduate and 75% of graduate students work either full-time or part-time to cover their expenses and/or gain valuable work experience. Thus, students often face challenges to fit their work and class schedule in the traditional learning method. To accommodate these students, online teaching mode is becoming a preferred alternative. COVID-19 pandemic also enhanced the demand of this mode. Electronic-learning (E-learning) is one of the best solutions that can help these students to get proper education. E-learning can be achieved in three modes: (1) virtual face-to-face, i.e., synchronous, (2) lectures are recorded and uploaded for the students, i.e., asynchronous, and (3) hybrid which combines both face-to-face and synchronous/asynchronous learning. However, teaching an engineering laboratory class is not suitable in the first two modes as laboratory classes are designed to give hands-on experience to the students. Hybrid method which includes hands-on experimental component is more appropriate for the lab classes. However, due to the pandemic, only few students could participate during the face-to-face session while others observed the experiment in the virtual classroom. Therefore, this added difficulty for majority of the students in understanding the methods and means of the experiments. To improve students better understanding, three components were added in the course design which were not included in the class before pandemic – (1) provided short video for each lab so that they can watch it before performing the experiment, (2) live video during performing experiments so that students can join synchronous lab session and ask questions/clarification, and (3) added quizzes on each experiments to make sure that the students can understand why and how each steps of a particular experiment were conducted. In this study, students' success is compared among three consecutive semesters, i.e., before pandemic (Fall 2019), at the beginning of the pandemic (Spring 2020), and during pandemic (Fall 2020). The study shows an excellent improvement in students GPA in Fall 2020 compared to the previous semesters. This paper will present the challenges to teach an engineering lab in hybrid/virtual mode.

Introduction

The demand of the E-learning or online learning has been increasing day-by-day^{1,2}. During COVID-19 pandemic (March 2020 to Present), the whole world continues education, from elementary to university, through online learning mode. Not only the academic education, all the scientific meetings, business meetings, and social meetings are using online mode. It was very hard for all the schools to change the conventional instruction mode to virtual (i.e., online) instruction mode overnight. Surprisingly, somehow all the schools - elementary to university as well as developed countries to underdeveloped countries, managed to finish the semester and/or school year. To convert a conventional face-to-face class into online instruction mode takes several semesters and need resources. Moreover, a huge percent of university faculties is not

interested in taking virtual classes. There are several reasons behind it such as: (1) lack of computer knowledge, (2) takes long time to develop an online course, (3) need more time to give online assignments, maintain webpage, and answering a huge number of emails, (4) no proper training, and (5) lack of resources. The scientific laboratories are more difficult to convert into online mode. The Science, Technology, Engineering, and Mathematics (STEM) program did research under few projects - demonstrated the lab activities can also be delivered online³⁻⁷. Some of the laboratory courses need to use heavy instrument to perform experiments are not easy to convert into online mode. There are several major questions will arise that must need to take care before converting a scientific laboratory course into online mode – What are the key points that helps students to improve their grade? How can we assess students while there is no control over students, i.e., open book and open resources? Can teamwork be maintained in an online mode? How can the pedagogical effectiveness be evaluated? Can online lab course maintain ABET (Accreditation Board for Engineering and Technology, Inc.) standard?

The main objective of this study is how to convert a mechanical engineering lab, where we need heavy instruments operation, into online mode that satisfactorily answer all the above questions.

ABET Student Outcomes and Course Objectives of MAE 374 and Student Outcomes:

In this research work, a Mechanical and Aerospace engineering lab course was selected – MAE 374: Mechanical Properties of Materials. The course is 300 level and cover 6-labs over the semester. The course objectives and ABET student outcomes of course are discussed below.

According to ABET, all Baccalaureate Level Programs seeking accreditation from the Engineering Accreditation Commission of ABET must have demonstrated student outcomes that support the program educational objectives. Attainment of these outcomes prepares graduates to enter the professional practice of engineering. There are seven student outcomes:

1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. An ability to communicate effectively with a range of audiences
4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
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
6. An ability to develop and conduct appropriate experimentation, analyze, and interpret data, and use engineering judgment to draw conclusions

7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Course objective of MAE 374 and Student Outcome

Objective of this course to understand the mechanical and physical properties of engineering materials and their relationship to structural elements; accuracy of measurements; statistical analysis of experimental data; writing professional laboratory/scientific reports.

Upon completion of the course, the student should be able to:

1. Observe the basic concepts of mechanical properties: Hooke's Law, Poisson's Ratio, torsion, bending moment and shear force diagrams, beam deflection and pressure vessels, photoelasticity.
2. Perform various tests and apply them to industrial applications for machine and structure designs.
3. Perform tensile, torsion and beam tests and apply them to characterize the material mechanical properties.
4. Able to acquire experimental data, analysis experimental data, statistical analysis of experimental data, accuracy of measurements, and compare the experimental results with the theoretical data.
5. Able to work as a team and write group lab/scientific reports.

Based on the above seven criteria of ABET, the course satisfies 1 to 3 and 5 to 7 student outcomes.

Teaching Methodology

The course was delivered and evaluated all the reports and exams by the author. This is a 1-unit lab and no lecture is included for this course. The students are supposed to read the lab manual and perform experiments as well as acquire experimental data. It is very hard to perform an experiment just after reading the lab manual even the lab instructor showed the process how to prepare test samples and operate the instrument. The students had suffered from several things including how to: perform experiments, acquire data, calculate data, and write lab report. To help the students, before performing experiment, a volunteer lecture provided to refresh the concepts/theory of the lab, how to perform experiment, how to acquire data, what to calculate, provided all the working formulae, what to cover in the lab report. Finally, demonstrate the instrument, i.e., how to operate the instrument, how to prepare a test samples (if necessary), how to perform experiment, and acquire experimental data. The lecture notes were uploaded on the course webpage. The same procedures were followed during the pandemic. In the middle of Spring 2020, the course was transferred into 100% online mode. Beginning of the Fall 2020, the labs were performed in hybrid mode. One student as a representative from each group could join in-person and all other students joined virtually watch live video while performing the experiments. It was very helpful for the students. Over the semester, all the students could get chance to perform experiment in-person at least one time and could have a lab visit. Moreover, when a group of students perform the experiment in the lab and all other students can see live video from home. The students whoever watching from home could see the instrument, every

steps of the experiments – preparation of test samples (if necessary), loading and unloading the test samples, how to operate the instrument to acquire the experimental data, and ask questions/clarifications. After taking 50% of the labs, the course was instructed 100% virtually due to the local situation of the pandemic. Basically, it was same as the Spring 2020 semester. After providing lecture/demonstrate an experiment, the lecture notes, a video on how to perform and acquire experimental data, all necessary experimental data, experimental graphs were uploaded on the course webpage.

The maximum student capacity of this course is 18 per section. Before pandemic, the students were split into several groups with 3 to 4 students for performing experiments and lab report writing. The groups are made for several reasons – (1) to make sure all the students get opportunities to perform the experiments, i.e., hands-on experience, (2) to help each other to perform experiment and acquire experimental data, (3) to learn how to solve engineering problems as a team, (5) to write a high quality report by the combined effort, and (6) to reduce load to write the lab reports. Evaluation method of the submitted lab reports as well as other criterions are described below based on semester, i.e., before COVID-19 pandemic (Fall 2019), beginning of the pandemic (Spring 2020), and during the pandemic (Fall 2020). Two evaluated lab reports, one of them is the first submission and other one is the second submission from the same group, are shown in the Table 1 to show how the students' grade improves if they get proper guidance and opportunity.

Assessment Before Pandemic (Fall 2019)

According to the course design, no lecture is needed, i.e., the students supposed to read the lab manual and perform experiments by themselves and submit the lab reports. But as mentioned before that the students were having difficulties to finish the lab properly. As a result, their grade grad was very poor. To help these students, a volunteer lecture is delivered before starting experiment as discussed above. Two criteria are used to evaluate the students, i.e., lab reports (70%) and the final (30%) exam. For the lab report evaluation, maintain a label, i.e., if the students do not meet that level, the lab reports are returned to the groups with comments. The students get one-week time to fix the lab reports. No points were cut for resubmission, i.e., full points are given if they can answer all comments to the point. This little extra help from instructor side, the students get several benefits – get the results as they expected on the basis of the theory, i.e., understand why/what they are doing, improve the overall concepts, more motivated, and improve grade by their efforts not by the curve. The final exam is a written test and need to answer 6 questions, i.e., one question from each lab. The questions are set as – (a) definition, e.g., what is tensile stress, (b) main concepts, e.g., draw a stress vs. strain curves and label the proportional limit, yield, tensile stress, and rapture stress, and (c) about instrument that were used for the experiment, e.g., why did you use an extensometer for the tensile test? The question (a) helps to know the definitions. The question (b) helps students to learn the main concepts. To make this question (b) easy to the students, a set of questions are added in the lab manual, which need to answer in the lab report. The question (c) use to make sure student engagement, i.e., the students become serious to know each step of the experiments. This basic

concept of the final exam is discussed on the day one so that students can understand what to do for this course to get a better grade. Table 1, shows few examples that demonstrates students' grade can be improved by extra effort from the instructor. The data were chosen randomly from Spring 2020. Almost 50% of the groups need this extra help in report writing for the first couple of reports. For the rest of the reports, students writing shows significant improvement and reduces the number of second review. It is not necessary to help only the particular group(s) all the time over the semester.

Table 1. The students' grades of 1st submission and 2nd submission (Spring 2020, Section-1 and 2).

Lab Report Writing Group	Grade (1 st Submission)	Grade (2 nd Submission)
1	70%	90%
2	72%	92%
3	75%	94%

Assessment Beginning of Pandemic (Spring 2020)

All the processes – lecture before starting each experiment and lab report evaluation were the same as before pandemic. The final exam was changed to online multiple choice (MCQ) instead of conventional written exam. It was hard to convert written exam to MCQ keeping in mind that the students may take help from books or online, i.e., open book and online resources. A couple of experiments were performed just before the pandemic started. All over sudden, the course had to convert the conventional face-to-face instruction mode to online mode, which was very challenging for both faculties and students. Specially, labs that need very heavy instrument with very complicated operating systems as well as sample preparation.

Assessment During Pandemic (Fall 2020)

Lessons learned from the first semester after pandemic started (Spring 2020), a little change was made in evaluation criteria, i.e., a quiz was added for each experiment. The quiz was taken after submitting each lab report. The quiz is designed to evaluate the basic knowledge of the students on the experiment and instrument that needed to perform the experiment. The performance in the quiz also assist the evaluate instructor's teaching effectiveness. It is important to know how well the instructor was able to describe the experiments in the virtual mode. It is assumed the lecture clearly demonstrated the experiment if majority of the students got more than 80% points in the respective quiz. If the quiz average was below 70%, instructor need to improve on lecture content and delivery. Quizzes grades varied between 70% to 100% in all the sections. However, few students needed one-to-one help to understand the theoretical concepts and experimental methods.

Results and Discussion

Base on the results of three semesters – (1) before COVID-19 pandemic (Fall 2019), (2) beginning of the pandemic (Spring 2020), and (3) during the pandemic (Fall 2020), we can answer the following questions that are the main objectives of this work.

What are the key points that helps students to improve their grade?

The student diversity is one of the biggest challenges. Students come from different backgrounds, nationalities, races, and some are first-generation college students. Moreover, many of them work and struggle to find enough time to study. . Most of them find report writing time consuming and challenging. Thus, the first draft often does not met report writing rubric standards. Therefore, we need to understand their differences and help them accordingly. This research show, there are two major things that can significantly help students to upgrade their grades. First, instructor need to restate the concepts, experiments and rubric and students require resubmission option to correct their mistakes. give one more chance to fix them. Second, they need little flexibility with submission deadlines. Although only few students need these types of help, their performance can significantly affect overall class performance.

How can we assess students while there is no control over students, i.e., open book and online resources?

Before the pandemic (Fall 2019) and beginning of pandemic (Spring 2020), according to the syllabus, students were evaluated on the lab reports and final exam. Before pandemic, the final was a written exam while the multiple-choice questions (MCQ) were set after the pandemic, i.e., from Spring 2020. In Spring 2020, a couple of labs were performed in-person and rest of the labs were performed via online. The CSU system took decision to stop in-person classes and go virtual, i.e., online instruction mode within two weeks. There were several issues arises from three sides – higher authority of the university, faculties, and students. One side, the higher authority was changing decisions frequently and provide lack of resources as well as lack of information. Other side, faculties were not ready to convert a course into online mode overnight while it takes several semesters and efforts to convert a conventional course to online mode. Most of the senior professors use conventional instructional mode and do not have adequate training to teach in virtual environment. Lastly, students were having problems such as many of them had no good computer, no internet, no suitable place to live and no money to survive. In addition, international students who went back home also challenged with time differences in instruction. Students can see the textbooks, online resources, and get help from their friends during the exams. There are two ways that may help to evaluate students effectively - giving MCQ and allowing 2 minutes per question. So that, only the students who know the answers can answer all the questions in the given time. On the other hand, if anyone needs help, i.e., needs to see the textbook or online resources, cannot answer more than 50% of the exam within the given time. In this study, per section, it was observed that only one or two students get above 80% and most of them received between 60% to 70%. The questions were same as written exams that were followed before pandemic except converted into MCQ format in Fall 2020. In the final exam students' performance improved than that of the results before pandemic. Before pandemic, most of the students got 25% to 40% and very few students get above 50% as shown in Figure-1.

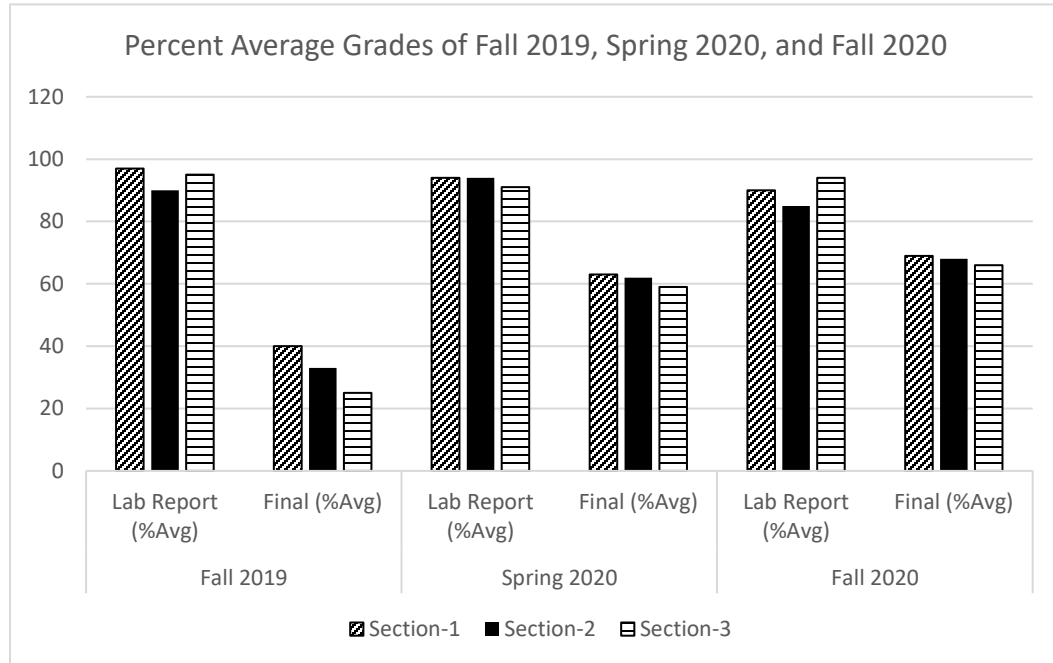


Figure 1. Percent average grade comparison among Fall 2019 (before pandemic), Spring 2020 (just after pandemic starts), and Fall 2020 (during pandemic).

Can teamwork be maintained in an online mode?

Before pandemic, students were made into small groups, three to four students were in a group, to perform experiments and write their lab reports. The same group system was continued during pandemic. Students had communicated with each other very well and submitted the reports in time as before pandemic. Students enjoyed working in groups since they did not feel alone as well as they had discussion among themselves. For additional assistance, they communicated with the instructor during the office hours or via email. The email is one of the key things for student success. The instructor was available almost 24/7 for the students. This study shows, there is no big differences before and after pandemic in teamwork.

How can the pedagogical effectiveness be evaluated?

During the pandemic, i.e., the online students' performances in their lab reports writing and exams were comparable or better to that of the performances before pandemic (Figure-1). Since the lab was synchronous so the students listened properly, just like one-to-one lecture. Students were free to ask questions during the lecture/demonstration as in-person mode. While in-person mode, many students did not follow the instructor due to the distance as well as some of the students were passive learners. Often, it can be noticed that some of the students were not engaged with the experiments because they think that whoever is responsible for data calculation

in the team needs to acquire experimental data. On the other hand, online students need to hear the whole lecture/demonstration. Otherwise, it would be hard for them to write their own assigned sections that need to write by themselves. The Figure-1 shows the comparison results.

Can online lab course maintain ABET standard?

Based on the above results (Figure-1), the students' performance in lab report writing was almost same as before pandemic. The grades in final exams are much better than before the pandemic. From Figure 1, the results clearly indicate that the course maintains ABET standard 1 to 3 and 5 to 7 as before the pandemic. The only lacking is the students can not operate the instrument in-person. If we can show a live video while performing an experiment may help better than pre-recording video. The live video may solve many issues including two major issues - the students can see the total process step-by-step and ask questions/clarifications if necessary.

Conclusion

The above results and discussion demonstrated the five important questions properly that were the main objectives of this study. This study also showed that the engineering lab that need heavy instrument can be delivered online instruction mode while maintaining ABET's accreditation criteria and important academic standards. Neither the rigor nor the quality of the course needed to be compromised. No significant differences were observed in the report writing for both before and after pandemic, i.e., face-to-face mode and virtual mode. The students' performance was significantly improved in the final exam after changing the exams' style, i.e., written mode to MCQ mode. The students' performance improved more after adding quizzes on respective experiments. This study shows that the students' performance in virtual mode was as good as traditional mode, i.e., face-to-face. So, the scientific/engineering labs, where we need heavy instrument, are pedagogically effective and can be offered in both hybrid and virtual instruction mode with keeping the ABET standard.

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