Navigating the COVID landscape with a Mechanical Engineering Junior Laboratory

Prof. Charles S. White
Department of Mechanical Engineering, Norwich University

Abstract

At the author's institution, all Mechanical Engineering undergraduate students are required to take a two semester laboratory course sequence covering topics in measurement and instrumentation. As with most hands-on instruction, the restrictions imposed by the COVID pandemic required significant adjustments to the course, especially the number of students that were permitted in the laboratory space at any given time. In this paper a comparison is made between the Fall semester course from before the pandemic (Fall 2019) and the same course during the pandemic (Fall 2020). Although COVID disruptions continue into 2021, the most dramatic adjustments to the course were made for the Fall 2020 semester.

This paper describes the course as historically taught and the course with the COVID adjustments. It also shares observations about how these changes may have benefited the students as well as detracted from the normal experience. Finally, a comparison is made between several of the relevant questions from the end of term student evaluation questionnaire.

Introduction

The COVID pandemic has forced many changes upon higher education. The biggest challenge has been to experiential learning since contact with others has been drastically limited. This has been felt in the engineering curriculum most dramatically in the conduct of laboratory based classes [1, 2, 3]. Numerous adaptations to laboratory based classes have been reported including mixed remote and in-person modalities [1], individual instead of group work [2], and computer simulation instead of hands-on experimentation [2]. Additionally, the structure of the class/lab set up and timing has been revisited in order to accommodate the need for reduced contact and increased distancing. Suggestions have been made to offer multiple shifts of a lab section, add concurrent sessions, introduce remote observation of live experiments, offer night and weekend lab shifts, and other solutions [3]. The efforts to adjust traditional approaches to meet the current needs are varied and worldwide [4].

This paper reports on the changes that were made between the 2019 Fall Semester (pre-COVID) and the 2020 Fall Semester (during COVID) to the Mechanical Engineering I Laboratory at the author's institution. The junior level students take two semesters of laboratory focused on experimentation and computer based data collection and analysis. There is then a third semester laboratory in the senior year focused on experiments in the fluid/thermal sciences. This paper is confined to the implementation of the COVID required changes to just the first semester junior-level course.

Laboratory Experiments

The eight traditional laboratory experiments as the course has been run for the previous 5 years are briefly described below.

1. **LabVIEW Introduction**: This lab session introduces the students to the LabVIEW computing environment and some basic LabVIEW programming. The students are also introduced to the use of the National Instrument data acquisition boxes (DAQs) and their interface with the computers. The LabVIEW software is located on four desktop computers in the laboratory room. A separate, electronic function generator is used to produce the voltage signal which is recorded by the end of the lab.

2. **Machinists Measurements**: The students become familiar with typical mechanical measurement devices such as Vernier micrometers and calipers, thread gages, gage blocks, and drill hole gages.

3. **LVDT Calibration:** The students learn to convert linear measurements to electronic signals using the LVDT transducer, signal conditioner, readout and connection to DAQ and computer data acquisition. The students calibrate the device with micrometers and gage blocks and then apply statistics to the measurement of 100 mass produced components.

4. **Load Cells:** The students are introduced to the technology of the strain gage and its application via a Wheatstone Bridge in load cells. They determine a calibration curve for a load cell and use it to measure an unknown mass.

5. **Thermocouples:** The students are introduced to the measurement of temperature with a thermocouple. The use of ambient air, ice water bath, and a cold junction compensator are used to determine accurate reference points. The measurement of an elevated temperature inside of a “hot box” is made and used to estimate the thermal resistance of various box lids.

6. **RC Filter:** The students are exposed to the concept of high pass and low pass filters and various first order system dynamics. They measure various time constants and Bode plot characteristics.

7. **Strain Gage Instrumented Beam:** This lab builds upon the understanding of strain gages from lab 4. A steel cantilever beam has two mounted strain gages to measure the longitudinal and transverse strain. The students use their Mechanics of Materials knowledge to convert these strains to a theoretical load. Using various weight loads on the beam a calibration curve is determined and compared with the theoretical value.

8. **Materials Property Testing:** The students are exposed to several materials testing techniques used on metals include: Tensile test, Charpy test, and Hardness testing. The comparison of some low strength steel, aluminum alloy and high strength steel are made.

Course Organization

The laboratory facility has 4 LabVIEW licenses so the course has been traditionally run with no more than 16 students divided into 4 groups for each of the 2 or 3 lab sections. The three-hour weekly laboratory period is supported with a once per week, 50-minute lecture that all of the lab sections attend together. In this lecture, background and theory for the upcoming experiments are discussed. Additionally, technical writing best practices are shared with the students. Several simple homework and pre-lab assignments are required of the students, as well.

Three different types of laboratory reports are required of the students to mimic the different reports that might be required in industry. These report types are as follows.

Formal reports are the type that would be sent to the company president at the conclusion of a major project, or that might be submitted to a technical journal for publication. These are typically 10 to 20 pages. These reports are written at a comprehensive level, assuming that the reader is technically competent, but not as knowledgeable of the specific project and physical phenomena investigated as the author, and thus requires a good deal of background and supplementary information to be able to grasp the implications of the project's result.

Technical Notes are of the type that, in industry, allows an investigator to update an immediate supervisor during the progress of a project. These reports are written with the assumption that the reader is familiar with the project and its techniques and terminologies.

Technical Memos are shorter correspondence that might be used to update a direct supervisor on the outcome of an experiment. Little background is included since the supervisor is assumed to be intimately knowledgeable about the project. The focus is on communicating the results. A simple memo format is given to the students.

Table 1 summaries the 8 experiments as they were conducted in 2019. All of the experiments were conducted jointly by the team (group of 3 or 4 students) and 6 of the reports were jointly submitted by the team. Each individual was required to write and submit one Technical Note and one Formal Report on their own. Also, note that the groups were assigned by the instructor and the students rotated groups each experiment.

Table 1. Lab Layout During Fall 2019

	Laboratory Experiment	Lab conducted by:	Report Type	Report written by:
1	LabVIEW Introduction	Team	Memo	Team
2	Machinists Measurements	Team	Memo	Team
3	LVDT Calibration	Team	Tech Note	Team
4	Load Cells	Team	Memo	Team
5	Thermocouples	Team	Tech Note	Individual
6	RC Filters	Team	Tech Note	Team
7	Strain Gage Instrumented Beam	Team	Formal Report	Individual
8	Materials Property Testing	Team	Memo	Team

COVID Adaptation

In the Fall of 2020, the university held on-campus classes that were also streamed online. Each classroom had a significantly reduced capacity and the on-campus students rotated between being in the classroom and attending online from their dorm rooms, depending upon the room size. This has been termed the HyFlex model [5]. About ½ of the students chose to stay off-campus, at their homes and just attend classes remotely. For the junior mechanical engineering laboratory class, the students were required to be on-campus and attend the lab sessions, in-person. The laboratory room capacity was reduced by the school to no more than 11 persons at a time to allow required increased personal distancing. This limitation required that the students conduct the experiments alone and not work in groups because the distancing could not be maintained. For some of the lab sessions, only 4 students were in the lab at a time. This then required up to 4 weeks for the entire class of 16 students to get through an experiment. Some of the other labs were shortened to allow completion in 90 minutes so that 2 cohorts of 4 students each could get through the lab in a weekly session. For three of the experiments, the students were given videos and data files from the instructors conducting the experiments. The students were told to treat these as if they were a silent lab partner to the instructor. They wrote the lab report as if they had conducted the experiments. The university went to entirely remote modality following the Thanksgiving break so that students would not travel back to campus after all of the interaction of travel and family contacts. Only the final lab (Material Property Testing) was held during this time and it was one of the video labs so it was easily done remotely by all of the students who, at that point, were off-campus.

Table 2 summarizes the modifications made to the laboratory portion of the course.

Table 2. Lab Layout During Fall 2020

	Laboratory Experiment	Lab conducted by:	Report Type	Report written by:
1	LabVIEW Introduction	Individual	Memo	Individual
2	Machinists Measurements	Individual	Memo	Individual
3	LVDT Calibration	Video - faculty	Tech Note	Individual
4	Load Cells	Individual	Tech Note	Individual
5	RC Filters	Video - faculty	Memo	Individual
6	Thermocouples	Individual	Formal Report	Individual
7	*Not conducted*			
8	Materials Property Testing	Video - faculty	Memo	Individual

First, notice that only 7 experiments were held. The Strain Gage Instrumented Beam was dropped in order to create more weeks for the reduced capacity constraint. Also, this experiment was a more advanced application of strain gages but they had already been introduced in Lab 4 (Load Cells). Secondly, four of the labs were conducted entirely by the individual and three were videos of the instructor conducting the lab. Also, the individual wrote all seven of the reports (4 Technical Memos, 2 Technical Notes, and 1 Formal Report).

Several observations can be made when comparing Table 2 with Table 1.

- Even though three of the experiments were video recorded for the students, each student had to conduct the complete experiment for the other 4 labs. This provided a significant amount of hands on time for each student when compared with the traditional approach of a group of up to 4 students conducting the 8 labs. Not only did each student need to do more hands-on work on average, there was no place for some students to hide behind their more aggressive classmate. It was much harder for any students to coast along during the lab period.
- Similar to the hands-on aspect, the students had much more writing to do, on average. This is because they each had to write all of the complete reports and not just contribute a section to the larger document from the group. This additional writing was probably very good for the students and the instructor felt that by the end of the term that the technical writing was better than a normal year, but no metrics were available to quantify this. As a note, the additional number of reports was really felt by the instructor since all labs are conducted by the regular faculty. This institution doesn’t have graduate students. There were a lot more lab reports to be graded!

- The use of some video recorded labs, although necessary for timing reasons, did not provide nearly as engaging an experience as the in-person labs. The students clearly didn't enjoy converting a video to a report. More thought needs to go into these video labs if they are required in the future.

Course Evaluations

At the end of this course, as will all the courses at the university, the students are asked to fill out an online, anonymous evaluation of the course. A total of 23 questions are asked and are graded on a 5-point scale indicating the level of agreement with the statement. Most of the questions are selected at providing feedback to the instructor about their performance. Typically, there is about a 50% response rate. Three of the questions have been selected here as most relevant to detecting differences in the student experience between the pre-COVID and during-COVID semesters. Those questions and the results are shown in Table 3. The score for each lab section is shown as well as the benchmark that the school uses of the overall rolled up value for the university. Two pre-COVID lab sections from 2019 are compared with the during-COVID result in 2020 of one lab section taught by the same professor. Only the lab sections taught by the author are compared in order to minimize variables. The typical standard deviation for each lab section score is about 1. Although statistical significance tests are not applied to this small data set, directional observations can be made.

Table 3. Student Evaluations for Selected Questions

	Fall 2020		Fall 2019/Sec1		Fall 2019/Sec2	
	n=7	COVID	n=7	Pre-COVID	n=9	Pre-COVID
	Score	Benchmark	Score	Benchmark	Score	Benchmark
The Instructor gave assignments that assisted students in learning the material.	**4.71**	**4.48**	**5.00**	**4.45**	**5.00**	**4.45**
To what extent has the course challenged you to do your best work?	**4.57**	**4.15**	**4.86**	**4.24**	**4.67**	**4.24**
As a result of this course, I would like to learn more about this subject.	**4.57**	**4.03**	**4.43**	**4.09**	**4.33**	**4.09**

As may be anticipated the scores for the first two questions (assignments assisting learning, and being challenged to do one's best) scored lower during the COVID accommodations than in the prior normal period. What is surprising is that the COVID experience did not turn off the student's interest in the subject matter. On the third question the students indicated increased interest to learn more about this subject than during a normal semester. Either the COVID restrictions gave the students just enough of a taste for measurement and instrumentation to kindle an interest or perhaps the students recognized that their experience was different than the norm and didn't want to miss something that they recognize they need. In either case, this is an encouraging indication for the students who came through the COVID restrictions.

Discussion and Conclusions

While the adjustments to the course execution was expected to be detrimental to the students' learning experience, there were some surprising benefits as well. Both the detrimental effects and these benefits are outlined below.

The negatives can be best described by what was lacking during the COVID pandemic: group interaction and Lab 6, the Strain Gage Instrumented Beam. Instead of group work, both in conducting the experiments and in writing the lab reports, each student was required to do these activities on their own. While one less laboratory was conducted, the one to be dropped was chosen as one that built upon concepts already introduced, not a lab with totally new technology. The students also experienced three lab experiments via video of the instructors conducting the lab. This was observed to be less engaging than the students actively participating in the conduct of the lab.

As mentioned above, some surprising benefits were derived from the accommodations. Firstly, each student, on average, had more hands-on time conducting the experiments than during a normal year where the work is split over a group of 3 or 4. The instructor also had an easier time to observe each student conducting the experiment and to provide feedback and assistance. Secondly, each student wrote the entire report for all of the labs, including those that they watched on video. This provided each with much more technical writing experience than typical and, again, gave the instructor more opportunity to provide feedback. Additionally, the students indicated through the end of term evaluation that they have a higher desire to continue to learn in this area than those from a normal semester. This is taken as a positive sign for the how the students received the course.

All in all, the tradeoffs to the student learning opportunities were felt to be appropriate and the students were sufficiently prepared to move on to the second semester junior lab course. Lessons learned include the benefit to the students from requiring more hands-on experimentation and writing of lab reports by each student, and not just a group output. This puts more requirement on the instructor but gives more detailed and tailored feedback to each of the students.

REFERENCES

[1] M. Javaid, D. Malooley, E. Wittenmyer, W. Cyburn, O. Henriquez, L. Pritchett, R. English, and X. Li, "Undergraduate Engineering Laboratories During the COVID-19 Pandemic," Proceedings of the 2021 ASEE Virtual Annual Conference, July 2021.

[2] J. Yao, “Using Collective Wisdom to Enhance Experimental Learning During the COVID-19 Pandemic,” Proceedings of the 2021 ASEE Virtual Annual Conference, July 2021.

[3] K. Alkhoury, A., Edrees, J. Sodhi, A. Borgaonkar, and P. Shekhar, “Investigating Students’ Expectations of Instruction in Engineering Laboratory Courses During the COVID-19 Pandemic,” Proceedings of the 2021 ASEE Virtual Annual Conference, July, 2021.

[4] J. Park, M. Park, K. Jackson, and G. Vanhoy, “Remote engineering education under covid-19 pandemic environment.” International Journal of Multidisciplinary Perspectives in Higher Education, vol. 5, no. 1, pp. 160-166, 2020.

[5] A. Earle, and A. Kennicutt, “Far From Normal – Student Struggles with Health and Social Interaction Persist Through Three Semesters of Education During the COVID-19 Pandemic,” Proceedings of the 2021 ASEE Virtual Annual Conference, July, 2021.