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Introduction to Engineering Virtual Labs - Challenges and Improvements

Dr. Gloria Guohua Ma, Wentworth Institute of Technology

Gloria Ma is a Professor in the Department of Mechanical Engineering and Technology. She has been teaching robotics with Lego Mindstorm to ME freshmen for several years. She is actively involved in community services of offering robotics workshops to middle- and high-school girls. Her research interests are dynamics and system modeling, geometry modeling, project based engineering design, and robotics in manufacturing.

Dr. John Peter Voccio, Wentworth Institute of Technology

Assistant Professor, Ph.D, Department of Mechanical Engineering and Technology, Wentworth Institute of Technology, Boston, MA 02115, Phone: 617-989-4258, Email: voccioj@wit.edu, Specialization in Mechanical Design, Finite Element Analysis and Superconducting Magnets

Mr. David E. Perkins, Wentworth Institute of Technology
Prof. Theodore Greene, Wentworth Institute of Technology

Work in Progress: Introduction to Engineering Virtual Labs - Challenges and Improvements

Abstract

Labs are a vital component to learning; hands-on labs reinforce the theory that the students learned in lecture. Whether you are conducting experiments, evaluating results, or comparing data, access to the labs on campus is vital to learning. However, due to the COVID-19 pandemic, accessing the labs on campus has been a challenge. In Fall 2020 first-year students were invited back to campus. Introduction to Engineering is one of the first-year courses having lab components. How to conduct the lab experiment to meet the course requirements and provide a good experience for the first-year students are challenges for instructors. To provide necessary hands-on experience and at the same time to reduce the overall risk of COVID-19 exposure, the first-year students Mechanical engineering labs were carefully classified to virtual and in person labs. This paper describes the design, implementation, and challenges of the virtual/in person labs. Student's feedback was collected to reflect their overall lab experience in this special time.

1. Introduction and Background

Labs are a vital component to learn engineering disciplines, since hands-on labs reinforce the theory that the students learned in lecture. With the development of modern technology, universities are changing from face-to-face education to remote web-based learning. However, it is a challenge to bring hands-on labs online due to the complexity of the labs, which include various equipment, materials, and resources. Setting up a web-system for e-education requires a significant amount of time, as well as the necessity of having a computer and other resources. Especially due to COVID-19, most universities closed their campus and moved most or all lectures and labs online. Lab instructors were forced to convert their physical labs to online with limited preparation time. It is important to highlight that only putting course content on the web, without using appropriate pedagogical models and principles, without appropriate means of communication between participants and instructors and without the use of modern information technologies to present the learning content, is not enough to fulfill educational goals [1].

There are many educators that have already tried diverse ways to provide remote or virtual engineering labs [2]. All types of laboratories offer certain advantages. Engineering students should be offered, through the duration of their programs, a balanced mixture of real, virtual, and remote labs [4]. Some researchers studied virtual/remote labs for various aspect: effectiveness of remote engineering laboratories and simulations [5], the role of virtual and remote labs in promoting concept understating [6], the evaluation of remote labs in terms of learning outcomes [7], comparing learning outcomes and student preferences for several different lab formats [8], the social involvement involved in remote experimentation [9], software requirements for remote laboratories [10] , and the technical approach of a dynamics remote experiment [11]. Some researchers studied the engineering labs for first-year students [12, 13]. Many educators reported their tips on converting biomedical engineering labs from in person to remote [14 - 24].

This paper describes our experience to design and implement the virtual labs. ENGR 1000 *Introduction to Engineering* provides incoming first-year students from four engineering disciplines (Biomedical, Civil, Electrical, and Mechanical) with an opportunity to learn about program areas in which they may interact in collaborative settings at Wentworth Institute of Technology (WIT). It is a 3-credit course with 1 hour lecture and 4 hours laboratory each week. Students rotate through four, three-week labs taught by faculty in the respective disciplines. The laboratory portion of this course is designed to introduce students to the various engineering disciplines such that the student can make a more informed choice of major in the first year, which is basic to all engineering disciplines, before moving forward into discipline-specific course work in the second year.

Our team teaches the Mechanical rotation. How to perform the lab experiment to effectively meet the course requirements, provide an enjoyable experience for first-year students and reduce the overall risk of COVID-19 exposure were challenges for instructors.

2. Revision of Mechanical Labs

The Mechanical Engineering lab module introduces the students to the fundamental knowledge of mechanical engineering field where students are introduced to the following topic areas: Strength of Materials, Thermal Energy Systems, and Kinematics and Dynamics.

Midway through the Spring 2020 semester, WIT transitioned to 100% online teaching due to the onset of COVID-19, and this modality continued through Summer 2020. Responding to student and parent requests, WIT introduced plans to return to limited in-person teaching for Fall 2020. These plans included adoption of CDC guidelines published at that time which required: face coverings to be worn at all times, individuals to maintain six feet of distance from others, and robust protocols for cleaning and disinfecting. To satisfy distancing requirements, a de-densified model for academic spaces was introduced leading to reduced student capacity in classrooms and labs. This created logistical challenges with the execution of several labs in the ENGR 1000 course. In addition, enhanced cleaning protocols raised awareness of the number of common touch points associated with individual lab activities. The combination of factors served as the basis for required revisions to lab activity plans for Fall 2020. As a result, the authors chose 4 labs and converted them to remote labs.

Material Property lab – tensile test – In person lab

The objective of this lab is to provide the students with a brief overview of topics related to strength of materials. Pre-COVID, we had a 2-hour period to complete this lab. The basic concept of stress and strain was introduced at the beginning of the lab, followed by the demonstration of the experiment. Students then formed a group to work on the experiment themselves and analyze the data right afterwards.

This was the only in-person lab since it is relatively easy to maintain 6 ft distance and is suitable for a single person to run the machine. To make the experiment smooth and maintain the safety protocol, two labs were allocated to complete the experiment. The first lab was to introduce the theory of tensile testing along with the equipment and tools used for this lab. The second lab was to do the in-person experiment. Students were divided into two groups and each group had 1 hour to complete the lab. The first lab was a virtual lab using Zoom, where students were introduced to the mechanical lab setting. After that the theory of tensile testing was introduced, and some videos were shown to students so that they understood the concept and gained familiarity with the Instron testing machine and some measurement tools. The second lab was the in-person lab. Students were divided into two groups, up to 8 students each, and each group worked on the experiment for 1 hour. During the lab session, a demonstration was done at the beginning of the lab. Following this, the first 4 students worked on the experiment, followed by the remaining 4 students. After the students completed the experiment, they were required to disinfect the machine so that next student could use it. Figure 1 shows students working on the experiment individually.

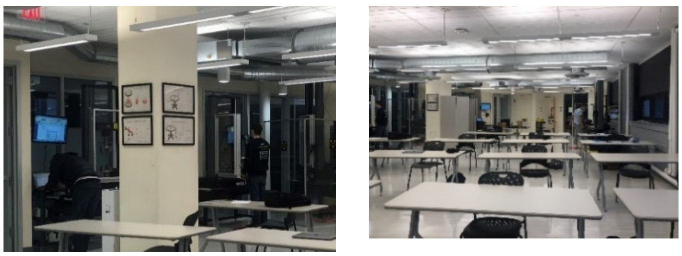

Figure 1. Tensile Test – in person lab

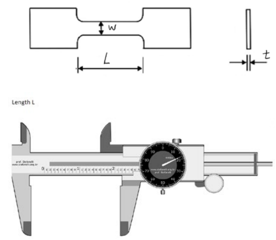

Figure 2. Tensile Test – Measurement

However, some students chose to work on the lab remotely for various reasons: CoVerified App (required by the University) was not cleared, health and safety concerns, etc. For these group of students virtual labs were done for them. To maximize mimicing the experience of the in-person lab, students watched the live demonstration of the experiment and practiced reading the dial calipers for the dimentions of the sample (shown in Figure 2). Students worked as a group of 2 to complete the data analysis. The following procedure was required for the remote lab:

1) Take the measurement of the sample. An example sample measurement is shown in Figure *2*.
2) Watch the demonstration video.
3) Two sets of experimental data was provided for two different materials.
4) Analyze the tensile test data using Excel.

Work and Power Lab – Virtual lab

During the Fall 2020 semester, this was a fully-online lab. This lab begins with a review of the engineering concepts of work and power. Along with the equations necessary to calculate each term, the basic units were reviewed. The energy required for a person of a given mass to ascend a set of stairs was reviewed. Hydraulic principles, including Pascal's Law of fluid mechanics, was also reviewed, as this is necessary to solve one of the problems.

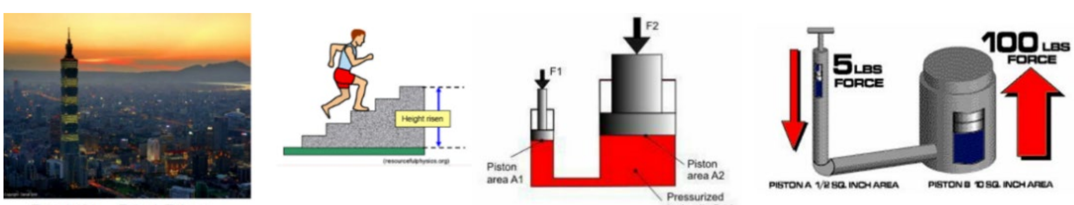

Figure 3. Vertical energy and power and Pascal's principle for hydraulics.

For exercises, the students were first asked to calculate the work required to lift a certain number of people of known weights to the top of a building. The height of the building was given in terms of the number of floors with each floor being a specific height. Then, after calculating the work, the students were asked to calculate the required power by dividing by the time in seconds. For these calculations, students were required to keep consistent units and perform conversions in order to get the final required power in units of horse power (HP).

During pre-COVID semesters, the students would perform an exercise where they would calculate their own horsepower by timing how fast they could walk or run up a 14-ft. high flight of stairs. Then, using their weight along with the known height and recorded time, they would calculate their own power in horse power (HP). However, during COVID-19, this aspect of the lab exercise was omitted.

Finally, the students were asked to determine the pressure and flow rate for a hydraulic pump needed to raise a fully loaded elevator. The hydraulic oil pressure was given, so the students needed to find the piston area based on knowing the maximum weight of the people on the elevator. Then, knowing the area, they calculated the cylinder volume and flow rate based on the allotted time.

Heat Engine Lab – virtual lab

The objective of this particular lab was to provide the students with a brief overview of topics related to Thermodynamics. The introduction to the lab consisted of a presentation that first defined isobaric, isothermal, and isovolumetric thermodynamic processes. Following this, the ideal gas law, $PV = nRT$ was discussed as a way to bridge student's prior knowledge with the new concepts. From here, the laws of Charles and Gay-Lussac, $V = \left(\frac{nR}{P}\right)T$, Boyle's Law, $V = (nRT)\frac{1}{P}$, and an isovolumetric relationship, $P = \left(\frac{nR}{V}\right)T$ were presented. The relationship of the equtions to the experiment was expressed visually by the following two images shown in Figure 4. The equipment required to conduct the lab as well as the overall steps involved to obtain the necessary data were then covered.

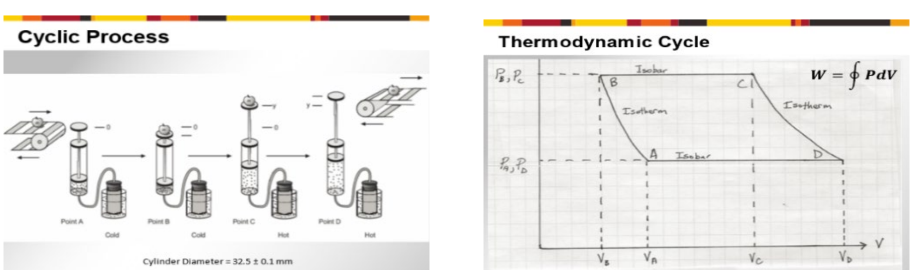

Figure 4. Heat Engine experiment and P-V diagram

In pre-COVID times, the students would have then worked together in groups of 3 to 4 to carry out the experiment and generate the resulting P-V graph for one thermodynamic cycle of the heat engine. This involved changing the temperature of the closed system by placing the aluminum cylinder in an ice bath, followed by boiling water. While this occurred, various amounts of mass were placed on the platform of the Heat Engine test apparatus and the volume of gas was determined. Simultaneously, pressure readings were also recorded. The equipment set-up can be seen in Figure 5.

The conversion to a fully remote, virtual version of the lab was done by having a faculty member conduct the experiment while taking still photos of the overall set-up conditions as well as close-ups of the Heat Engine apparatus and the pressure gauge. As the conditions of temperature and mass applied to the Heat Engine were changed, the 'data' was again recorded with the still photos. Upon completion of the experiment, the still photos were integrated into a video with the use of Adobe Spark. Captions were added where necessary, and background music was selected. Examples of screen-captures from the videos are shown in Figure 6.

Figure 5. Equipment setup

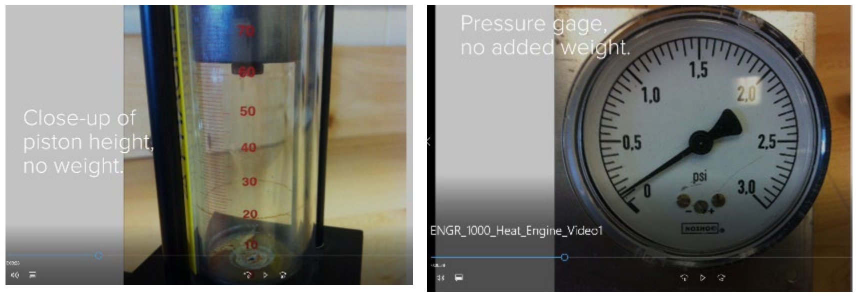

Figure 6. Screen-capture of the measurement

With the use of the Zoom Breakout room feature, students were placed in groups where they worked together (remotely) to view the video in order to obtain the necessary data. Some groups did this as a collaborative effort while others worked individually and then compared their data once it had all been obtained. As the students were working through the videos, the instructor was able to join the breakout rooms to answer questions and provide guidance.

With the data gathering complete, the students continued working in the breakout rooms to analyze their values and results within Excel. The majority of the time, one person from each group would use the Zoom share screen feature to present their excel spreadsheet so all members could work together on the data analysis. Once everyone was satisfied with the results, the spreadsheet and corresponding graph(s) were uploaded to the learning management system for instructor review and grading.

Kinematics and Dynamics lab – Virtual lab

This lab begins with a general presentation covering four-bar linkages and introduces the Grashof Criterion. Students then use the software, Working Model [25], to simulate the action of a windshield wiper mechanism to demonstrate the conversion of rotatory input to oscillatory output using a four-bar linkage. Following development of a functioning model, in the pre-COVID setting, students would then fabricate a prototype using a kit consisting of links of various lengths and small fasteners to form the joints. It was decided that the number of small parts and tools required to be shared during the hands-on portion of this lab would pose a challenge for the required cleaning protocols. As a substitute, we decided to eliminate the hardware task and place more emphasis on data collection and analysis techniques.

The lab begins by walking students through the process of building a model of a simplified windshield wiper using four links of predetermined length with the short link connected to a rotary driver (motor). Initially, the links are arranged in a manner that violates the Grashof Criterion causing the model to fail. Students are then told that they need to apply what was learned in the lecture to fix their model. Typically, students fix their model by either relocating one of the ground joints or changing the length of one link.

In pre-COVID times, this is where students would transition to the hardware task. Instead, students were instructed to add an extra point shown in Figure 7 to the outer extent of the windshield wiper link and to this point add a Measurement attribute for Velocity. Now when the model was executed, velocity data was collected for this point. Students were then guided through the process of downloading a *.txt file and converting this to a Microsoft Excel *.xlsx file. Students were then asked to plot the velocity vs time data using techniques learned in prior labs. The ability to correctly depict experimental data is a key requirement of subsequent School of Engineering labs and a goal of this course to adequately prepare students for those requirements.

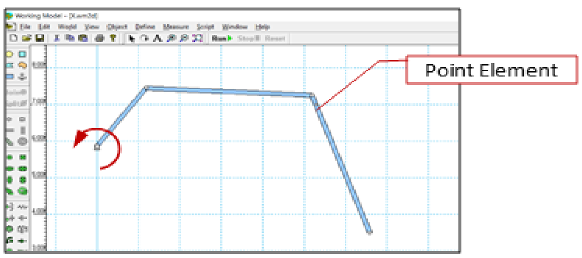

Figure 7. Working Model four-bar linkage simulation.

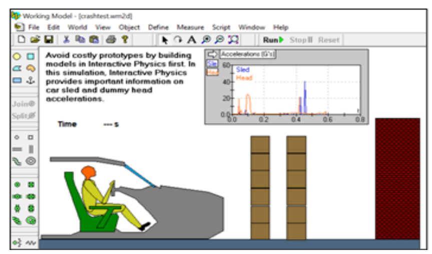

Figure 8. Working Model vehicle crash simulation

Some students found the windshield wiper model to be a bit simple. For ambitious students, an extra credit component was added to this lab based on a pre-defined Crash Test simulation from the vendor as illustrated in Figure 8. As provided, the simulation applies vehicle initial velocity conditions of 11 m/s and monitors the acceleration of the occupant's head as the vehicle collides with various structures. Students were instructed to collect occupant head acceleration data for five vehicle initial velocities ranging from 11 m/s to 3 m/s. Acceleration data was tabulated and graphed and then compared with head injury threshold data from the Wayne State Tolerance Curve cited by Greenwald [26].

3. Student Survey Results

A survey was sent to students after they completed the mechanical lab module. In total, 39 students completed the survey questions.

Survey Question 1 ~3 results are shown in Figure 9. Q1: In terms of the preferred learning format for learning new content, 92% of the students chose in person while the remainder chose online. As to the preferred primary studying/learning format (Q2), 33% of the students like to study alone, while 8% indicated they like to study in a group. The remaining the remaining 59% of students chose a mix of alone and in group. Q3: What overall rating would you give the module? There were 62% of students who thought the module was very good / excellent, while

28% selected good, and 10% rated it as fair. Survey results of questions 4 ~ 5 are shown in Figure 10. Q4 asked the students to rate their level of enjoyment with the labs. Student responses showed that 67% enjoyed the mechanical lab portion, while 33% did not enjoy the lab; however, they indicated that they had gained new knowledge about mechanical engineering. When students were asked about their ideal structure for mechanical labs, (Q5), 39% chose 100% in person. The majority of students chose some combination of in-person and online lab structure with. 36% choosing a 75% in person / 25% online combination; 18% chose 50% in-person / 50% online, and the remaining 7% selected a 25% in-person / 75% online combination. No student chose 100% online for the lab. This was mainly determined by the content of the lab. If there are simulation-based labs, students might not feel the need to come in-person to work on the experiment.

Survey results of question 6 is shown in Figure 11. The reasons that students did not enjoy the lab module (Q6) spread out widely. The top three are: the lab instructions were not clear (23%), they feel lonely (18%), and the lab instructions and questions were too hard to understand (14%). Other responses include bad internet connection, technology issue (low resolution display of the content in screen), etc.

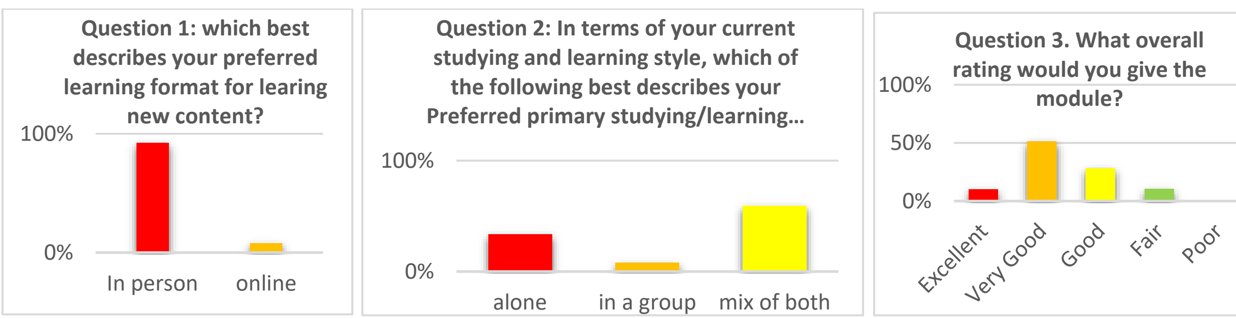

Figure 9. Survey results for Questions 1 ~ 3

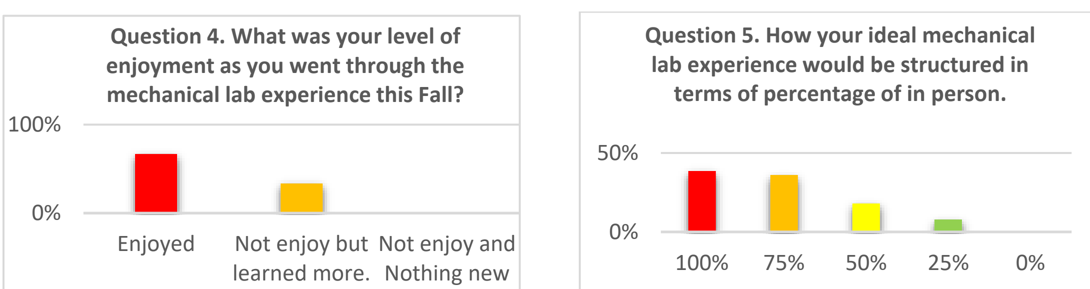

Figure 10. Survey results for Questions 4 ~ 5

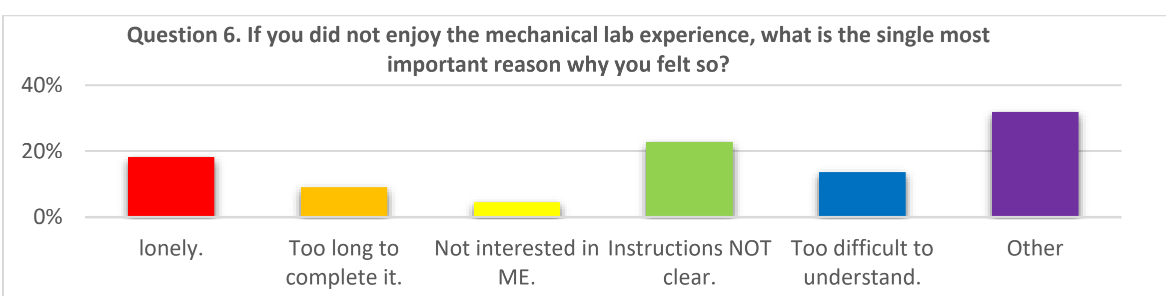

Figure 11. Survey results for Questions 6

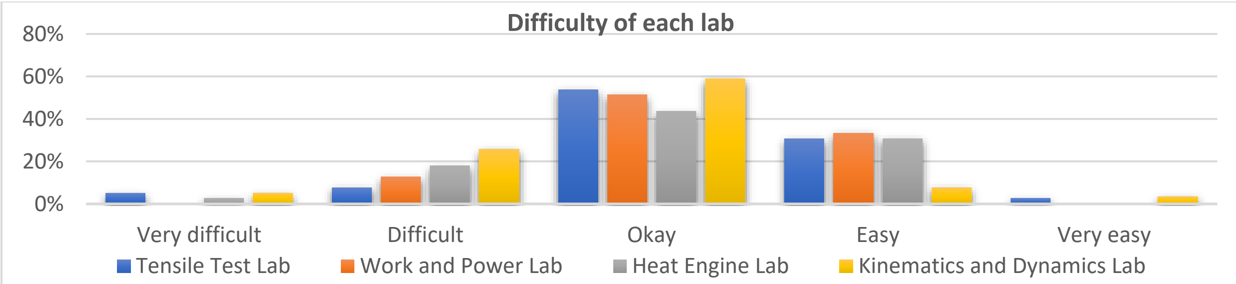

Figure 12. Difficulty of each lab

Due to COVID-19, the lab was changed slightly to better suit an online learning environment. The difficulty of each lab was surveyed too. The results show that the level of difficulty for each lab is slightly different (Figure 12). For the Tensile test lab, 54% of students thought the level of difficulty is okay, 12% thought it was difficult or very difficult, and 34% believed it was easy or very easy. For the Work and Power lab, 51% thought it was okay, 13% thought it was difficult or very difficult, and 34% thought it was easy or very easy lab. For the Heat Engine lab, 44% thought it was okay, 21% thought it was difficult or very difficult, and 35% thought it was easy or very easy. For the Kinematics and Dynamics lab, more than half of the students (59%) thought it was okay while 31% thought it was difficult or very difficult, and 10% thought it was fairly easy.

4. Discussion

In-person vs. Online: From the survey it was found that the majority of students prefer in-person labs and their preferred ideal lab structure is at least 50% in-person labs (Figure 9). This is because two of the labs did not use any school equipment (Work and Power, and Kinematics and Dynamics). However, 39% students prefer 100% in-person labs. A student commented: “Due to most mechanical labs being online made it less interesting doing each lab because I wasn’t able to do any physical activity”. Physical hands-on experiments play an important role in engineering education. A simulation-based lab still cannot fully provide the experience and lab skills that are provided by hands-on in-person labs [16]. Especially for those students who learn better by doing.

Data Collection vs. Analysis: With the lab module being revised for on-line teaching, the focus shifted from data collection to data analysis. Before COVID-19, students focused more on working on the experiment and collecting data. Sometimes the data analysis was done afterwards on their own. Oftentimes, it was found that students had problems working out the correct answers. While in virtual labs, they analyzed the data in class. We observed that students’ data analysis skills improved the most which is similar to the conclusion presented in [6], this is confirmed by the quality of students’ lab assignments as well.

Collaboration/Teamwork: One of the reasons that students did not like virtual lab is that they felt lonely (18%). In typical lab settings, students would be expected to work in groups. However, due to COVID-19 all work was done individually. To encourage students’ collaboration, breakout rooms within the Zoom platform were used. Students were placed in groups and assigned to breakout rooms where they worked together remotely. The breakout room feature helped foster collaboration between students.

5. Conclusion

Due to COVID-19, accessing the labs on campus was a challenge. To provide necessary hands-on experience and at the same time reduce the overall risk of COVID-19 exposure, the ENGR1000 Mechanical labs were carefully revised to 3 virtual labs and 1 in-person lab. The labs were successfully performed. There were 62% of the students who thought the module was very good / excellent, while 28% thought the module was good, and 10% rated it as fair. In terms of the level of enjoyment of the labs, 67% of the students enjoyed the mechanical lab module, while those who did not enjoy it still felt they had learned more about mechanical engineering. Even though students feel the virtual labs are good, most of them still prefer in-person labs. For first year students, in-person labs will be a better choice for them. They can become familiar with the University environment quicker and have a better overall college experience.

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