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Utilizing Depth Cameras for Active Remote Participation in Lab and Project Activities.

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Abstract

This work evaluates and compares student satisfaction with two First Year Engineering lab projects delivered remotely versus in-person. Different approaches were taken for the two remote projects: while the Bridge project used mail-out kits, which allowed the remote students to build their own bridges and test them to failure, the Robotic Arm project utilized sophisticated Intel RealSense D435i depth cameras, which gave the students the ability to remotely measure the 3D position of the robotic arm located in university labs. This 3D feedback was then used to modify the instructions sent by the remote students to the robot. The projects were delivered to 115 first-year engineering students in nine LAB sections: three in-person-only, three remote-only, and three mixed. Performance of each method was quantitatively assessed based on exit survey results, and scores from various student populations were compared using two-sample *t*-tests. The results suggest that using mail-out kits achieved similar student satisfaction levels regardless of the class format (means of 4.10 to 4.65 out of 5), but the method needed a lot of time and tedious labor. Connecting remotely to the lab and using depth cameras, on the other hand, received significantly lower scores than doing the project in person (3.58 versus 4.20), which suggests that true hands-on experience may be important. However, the depth camera method exposes students to sophisticated modern tools and requires nothing mailed out. The authors view the 3.58 score as promising, considering that the method was employed for the first time, and can likely be improved on subsequent implementations. If this is the case, the depth camera method can become an attractive tool for remote labs and projects, both within and outside engineering. The method is rather inexpensive and can be applied to various experimental setups, whenever 3D location of objects needs to be visualized and measured remotely.

Introduction

Collaborative projects and laboratories are examples of high-impact educational practices as described by Kuh [1] . They are also examples of both active learning and collaborative learning [2] , which have been shown to increase student learning and conceptual understanding of basic concepts (as reviewed in [2]). Therefore, they are an important and necessary component of any high-quality engineering education program.

In traditional in-person engineering education, projects and labs typically utilize existing laboratory equipment and manufacturing capabilities of the school. In recent years, however, there seems to be a growing demand to make these interactive projects and laboratories available for remote participants, either as a part of an online engineering programs [3] , [4] , or as virtual labs focused on manufacturing technology and closely related to industrial applications [5] . Most recently, remote laboratories and project became a necessity due to the global pandemic.

This paper describes an effort to adapt two existing first-year engineering projects to a remote format. Engineering Techniques (ENGR-111) is a highly interactive engineering course taken by all first-year engineering students. The main course objectives are to help with transition to college, to better understand the engineering profession, and to develop basic engineering and communication skills. When done right, this course should get students excited about the engineering profession and about the university's engineering programs.

Incoming engineering students love hands-on activities that involve creativity. Therefore, at the core of ENGR-111 are two four-week team projects, which are performed in small LAB sections, capped at 15 students. Student teams of three to four are challenged with tasks such as designing and building a lightweight bridge or designing and programming prescribed motion of a robotic arm. These types of projects have been consistently rated highly by the students on exit surveys.

Because of the 2020 pandemic, only about half of the 115 incoming first-year students could attend the ENGR-111 projects in person, while the remainder had to attend remotely. An urgent need arose to modify two selected projects in such a way that both in-person and remote students could participate in an active and meaningful way. The projects described herein address this need. They were designed in the summer of 2020 and implemented in the Fall 2020 semester. This unusual situation was also used as an opportunity to evaluate and compare in-person vs. remote participation in the two projects modified for remote participation.

Forming LAB Sections and Teams

The 115 first-year engineering students were from Biomedical, Chemical, Civil, Electrical, Mechanical, Robotics Engineering and Engineering Undecided majors. About half of the students declared the need to attend classes remotely while the other half attended in person. The students were divided into nine LAB sections of about 13 students: three sections with only in-person students (IP), three with only remote (R), and three with a mixed population (Mix). The student majors were not considered when forming the sections, and therefore can be considered random. The teams formed in each section (three to four students each) were intentionally created as interdisciplinary by the instructors.

Description the Projects

Two projects were redesigned (from previous years) to add the remote participation option: Instrumented Bridge project (Bridge) and Robotic Arm project (Robot).

The Bridge project challenged the students to design, build and test a lightweight truss bridge, like the one shown in Figure 1. An overview of the in-person project schedule is presented in Table 1 below. In order to provide meaningful and active remote participation, mail-out kits were assembled and sent to each remote participant (this was a tedious and time-consuming process). The kits included balsa wood, aluminum plate, glue, eyebolts with nuts and rubber tie downs (to hang the bridge load), and safety glasses. The remote students were asked to come up with their own method to hang a bridge load of known varying weight so that they could

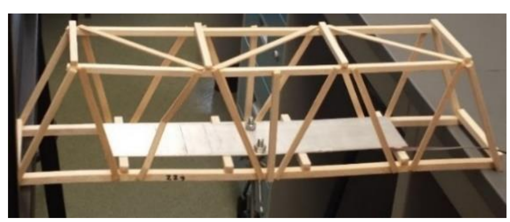
Figure 1 Instrumented bridge

determine the bridge load at failure. It was decided not to mail out any strain gauges or electronic components. Still, the remote students were able to simulate circuits in the same software as the in-person students. Both populations also used free engineering software (Risa 2D) to perform design calculations.

Table 1 Overview of Bridge Project Schedule

Week	Topics	Specific Goals
1	Project Introduction; Building Simple Trusses; Introduction to RISA2D	1) Project background and overview; 2) Build and test a king post truss structure; 3) Become familiar with using a design software, RISA 2D; 4) Develop preliminary design of supporting truss structure for the bridge model
2	Building Truss Bridge Model	1) Build a truss bridge model
3	Introduction to circuits and electrical components; Building a simple circuit; Introduction to NI Multisim™	1) Introduction of Ohm's Law, circuits, and common electrical components; 2) Create a circuit with a constant resistor and a potentiometer; 3) Become familiar with using NI Multisim™ to simulate a circuit; 4) Introduction of strain gauge and Wheatstone bridge circuits
4	Building Strain Gauge Circuit	1) Build a Wheatstone bridge strain gauge circuit

While the remote students did work in teams (remotely), each student built and tested their own bridge. In-person bridge competition was replaced with an honor-based competition, with the remote students recording videos of their bridges reaching their load limit.

The Robot project challenged the students to program a robotic arm (Figure 2) to perform a sequence of precisely defined motions to grab and move small objects between two prescribed locations. It also demonstrated how an sEMG sensors can be used to activate motion of the robotic arm by flexing a muscle.

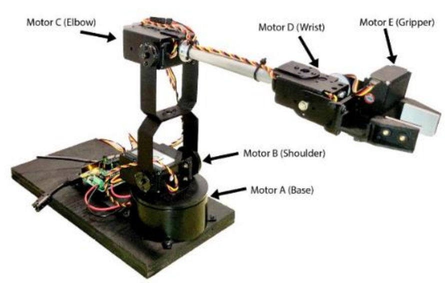

Figure 2 Robotic arm

Figure 3 Depth camera (3.5" wide)

Since mailing the robots to students would have been prohibitively expensive, an innovative method to engage remote students with the robot had to be developed. This was accomplished by purchasing Intel RealSense D435i depth cameras (Figure 3), which were installed in the instructional labs, and gave students the ability to evaluate 3D position of the robotic arm. The software that came with the depth cameras allowed the students to rotate the 3D view and to measure the robotic arm position in 3D (Figure 4). The robotic arm, the camera, and the camera software were first set up by the instructor, and then the remote students were given access to the depth camera software on the lab computers using Zoom share desktop feature. Robot programming was done by the students remotely, and the code written by the students was uploaded to Arduino and executed by the instructor. Students were then able to compare the actual robot position with the intended position, and modify the code, as needed.

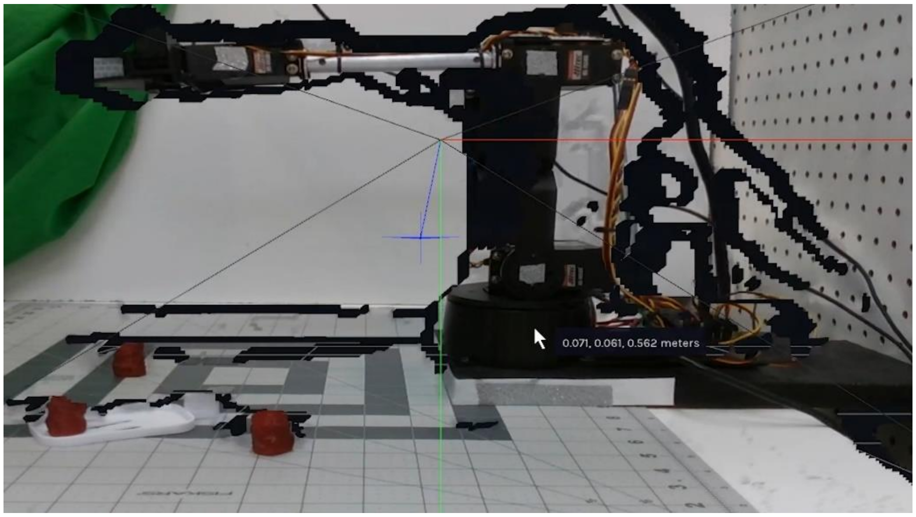

Figure 4 View of the robotic arm through Intel RealSense Depth camera (in software window).

An overview of the in-person and remote project schedule is presented in Table 2 below.
It can be seen that despite half of the students participating remotely, most of the activities were the same for in-person and remote students. The most important differences were that in-person students could physically touch the equipment, while the remote students only interacted with it via computer interface. On the other hand, the in-person students were not introduced to the depth cameras at all.

Table 2 Overview of Robot Project Schedule

Week	In-Person	Common	Remote
-3 (Seminar)	Overview of Robotic Terms: Joint Types, End Effectors		
-2 (Seminar)	Quiz, Introduction to Robotics: Sense, Plan, Act; Sensor Types, Arduino Basics, Servo Motors, PWM, H-Bridge		
-1 (Seminar)	Getting Started Arduino Software installation	Quiz, AL5D Robot Arm full Overview, Challenge Overview, Kinematics 2 DoF Arm, Algorithms, Arduino Programming / Simulation, Easy Calibrate software	Intro to RealSense Depth Cam Software (video) and Getting Sta Arduino Software installation
Lab 1	Student laptops connect to Robot Arm	Lab Goals, Team Assignments, Lab Safety, Tinkercad Circuits, Perform Dimensional Measurements of the Robot, Calibrate Arm Servos	Remote labs using Zoom and In RealSense Depth Camera
Lab 2		Gripper Servo Calibration and Kinematics, Base Angle Kinematics, Algorithm for object manipulation, Program for objects	
Lab 3	Programming the sEMG sensor to control the robot	Intro to the sEMG sensor and analog sensors, Programming to pick and place additional objects, repeatability	Simulation of the sEMG senso
Lab 4		Programming: balancing arm velocity with repeatability	

Assessment Tools

The assessment of this project compared student feedback collected on a detailed exit survey from the populations of in-person (IP) versus Remote (R) students and inferred whether or not these populations performed differently. While the exit survey had many prompts (about the entire ENGR-111 effort), only the prompts listed in Table 3 below were selected and analyzed for the purpose of this assessment. The survey was requested from all 115 students and completed by 97 (84%).

Table 3 Exit survey prompts selected for the analysis.

Prompt	Answer Type
1. Type of LAB Participation	'Remote' or 'In-Person'
2. Type of LAB Section	'All Remote', 'All In-Person' or 'Mixed'
3. Rate Project 1 (Bridge)	Numeric, from 1 (worst) to 5 (best)
4. Rate Project 2 (Robotic Arm)	Numeric, from 1 to 5
5. Any comments on Project 1? What would you like changed?	Text answer
6. Any comments on Project 2? What would you like changed?	Text answer
7. PROJECTS classes: What worked? What did you find interesting and/or useful?	Text answer
8. PROJECTS classes: What did not work? What did you find least interesting and/or frustrating?	Text answer

All numeric responses (Prompts 3 and 4) were analyzed using a two-sample *t*-test to determine the likelihood of the In-Person and Remote populations being statistically different (threshold *P* value of 0.1 was selected). In addition, all text responses were compiled to identify common trends in the Remote and in the In-Person populations.

Assessment Results

The analyzed results comparing the IP and R populations are presented in Table 4, where the mean response values, their difference and the *P*-values are listed ($P<0.1$ listed in bold).

Table 4 In-Person vs. Remote populations

	Bridge Project	**Robot Project**
Mean IP (49 students)	4.38	4.20
Mean R (48 students)	4.23	3.58
Difference	0.15	0.62
***P*-value (t-test)**	0.36	**0.01**

More granular analysis was also performed (on the same data), which compared four sub-populations with one another. Table 5 defines the four populations and their average responses. Similar statistical methods were used to analyze each pair of populations from the four listed in Table 5, and the results are presented in Tables 6 through 11.

Table 5 Four additional populations and their mean values.

Label	Population (number of responses)	Bridge Project	Robot Project
IP-All	In-Person students in All In-Person sections (32)	4.22	4.00
IP-Mix	In-Person students in Mixed sections (17)	4.65	4.53
R-Mix	Remote students in Mixed sections (10)	4.10	3.60
R-All	Remote students in All Remote sections (38)	4.26	3.58

Table 6 IP-Mix vs. R-All

	Bridge Project	Robot Project
Mean IP-Mix	4.65	4.53
Mean R-All	4.26	3.58
Difference	0.38	0.95
***P*-value (t-test)**	**0.08**	**0.00**

Table 7 IP-Mix vs. R-Mix

	Bridge Project	Robot Project
Mean IP-Mix	4.65	4.53
Mean R-Mix	4.10	3.60
Difference	0.55	0.93
***P*-value (t-test)**	0.11	**0.07**

Table 8 IP-All vs. IP-Mix

	Bridge Project	Robot Project
Mean IP-All	4.22	4.00
Mean IP-Mix	4.65	4.53
Difference	-0.43	-0.53
***P*-value (t-test)**	**0.07**	**0.08**

Table 9 IP-All vs. R-Mix

	Bridge Project	Robot Project
Mean IP-All	4.22	4.00
Mean R-Mix	4.10	3.60
Difference	0.12	0.40
***P*-value (t-test)**	0.72	0.42

Table 10 IP-All vs. R-All

	Bridge Project	Robot Project
Mean IP-All	4.22	4.00
Mean R-All	4.26	3.58
Difference	-0.04	0.42
***P*-value (t-test)**	0.83	0.16

Table 11 R-Mix vs. R-All

	Bridge Project	Robot Project
Mean R-Mix	4.10	3.60
Mean R-All	4.26	3.58
Difference	-0.16	0.02
***P*-value (t-test)**	0.60	0.97

The results of the analysis of the text prompts 5 through 8 (see Table 3) are presented in the Discussion section below.

Discussion

Several conclusions can be drawn from the presented results. Looking at the two large populations (Table 4), it can be seen that the means for the In-Person population are consistently higher than the respective means for the Remote population, with the largest difference of 0.62 for the "Robot Project" (P = 0.01). Interestingly, the "Bridge Project" responses were not statistically different (P = 0.36). This suggests that the mail-out kit approach worked very well. Examining the results for sub-populations (Tables 6 through 11), both projects were rated the highest by the IP-Mix population (Table 5), which rated the projects higher than the IP-All population by 0.23. Interestingly, Table 8 shows that these differences were statistically significant for both projects (P = 0.07 and 0.08). One explanation could be the much smaller number of students present in the lab for the IP-Mix students (other students were participating remotely). However, the differences between R-All and R-Mix were not significant (Table 11).

The largest observed difference was between IP-Mix and R-All for Robot project (Table 6). While in-person students rated the project at 4.53, the remote students rated it at only 3.58. But, to keep things in perspective, even the lowest score (3.58) can be viewed as a successful run, especially since it was the first-time implementation.

Student answers to prompts 5 through 8 may shed some additional light on the presented discussion of numeric results. After all text answers were compiled into thematic groups, the following patterns emerged:

1. In-Person (IP) students praised both projects, especially for their hands-on approach, teamwork, and creativity. Several students explicitly mentioned being in-person as a strong positive. The single most common criticism was that they had received insufficient introduction to coding the robot.
2. Remote (R) students liked the bridge project mostly because of hands-on the kits and using Risa 2D software (both being active components). Many students were excited about teamwork, even though it was in remote format. The opinion on the Robot project was quite mixed, with a few students being enthusiastic and some others being critical (see quotes below). Difficulty with coding the robot and using depth camera was mentioned by several students. Some R-Mix students complained that they did not get enough attention from their instructor (who was teaching in a hybrid mode).

Here are a few representative quotes from students participating remotely (language not corrected):

- "Both projects were fairly interesting and challenging. I enjoyed trying to figure out equations as homework. I wish I would have been able to participate in-person because the hands-on aspect of engineering is really important."
- "I really enjoyed the bridge project, and having to meet with my partners outside of class established a community for me."
- "The real sense camera was really cool, and being able to code and control the real robotic arm in the widener laboratory was great. I also thought that sending out a materials kit to the remote students was awesome as well, I all for hands on experience."

- “I felt that some aspects of the robot lab were difficult to do remotely. For instance, it would have been extremely difficult to sense depth even with the cameras and oral notes from the professor.”
- “Remotely completing projects was oftentimes difficult as there was little in the way of clear guidance, and could not easily speak with professor for instructions through remote format”

Conclusions, Impact and Limitations

The two presented methods made it possible to engage remote students in high-impact educational practices of two collaborative, hands-on, team projects. Both methods received praise from the students for being interactive and fostering teamwork.

The results presented in this work suggest that the simple idea of mail-out kits did a very good job with all student populations, regardless of the class format (average scores between 4.10 and 4.65). However, this approach is tedious and time consuming, with the required resources growing proportional to the size of the student population (one kit per each student, not per team).

The method of connecting remotely to the lab and using a sophisticated depth camera received significantly lower scores than doing the same project in person (score of 3.58 versus 4.20). However, the score of 3.58 (out of 5) is still quite promising, especially considering that this method was much more involved, that it was implemented for the first time, and led by instructors most of whom had little prior experience with a depth camera or its software. It is reasonable to expect that the observed score gap would substantially narrow on subsequent implementations. The method has a clear advantage of not having to purchase and mail multiple lab kits. In addition, it exposes students to sophisticated and modern tools.

The depth camera method, combined with sharing desktop on Zoom, can be applied to disciplines outside engineering, whenever remote students need to obtain measurable information about the 3D location of the objects of interest. At $199 (as of summer 2020), these cameras are not prohibitively expensive.

One limitation of the analysis presented herein is that most LAB sections were taught by different instructors. While there were two sections (one Remote and one Mixed) taught by the same instructor, the number of students was too low for any meaningful analysis. It would also be interesting to know if student majors contributed significantly to the ratings of the Robot project. Unfortunately, this information cannot be obtained, because the exit survey given did not ask the students about their majors.

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