2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #32482

Teaching and Managing Remote Lab-based Courses

Dr. Mohamed A. S. Zaghloul, University of Pittsburgh

Mohamed A. S. Zaghloul was born in Cairo, Egypt, in 1987. He received his B.E. degree in Electronics and Electrical Communications Engineering in 2009, and his M.Sc. degree in Engineering Physics in 2012, both from the Faculty of Engineering at Cairo University. In 2019, he received a Ph.D. from the Electrical and Computer Engineering department of the University of Pittsburgh, in developing optical fiber sensors for monitoring harsh environments. Since 2019, he has been appointed as an Assistant Professor in the same department of the same school. Zaghloul is a recipient of multiple research and teaching awards, and since 2016 he has been appointed to the Postgraduate Research Program at the National Energy Technology Laboratory (NETL) administered through Oak Ridge Institute for Science and Education (ORISE).

Prof. Amr Hassan, University of Pittsburgh

Dr. Amr Hassan (also know as Amr Mahmoud) received his B.Sc. degree in Electronics and Electrical Communications Engineering and the M.Sc degree in Engineering Physics from Cairo University, Egypt, in 2011 and 2015, respectively. He earned his PhD in Computer Engineering from the Electrical and Computer Engineering Department at the University of Pittsburgh, USA. Currently, he is an Assistant Professor with the same department, since August 2019. Dr. Hassan's primary focus is on education development and innovation. His Research interests include, but not limited to: Machine Learning, especially Deep Learning, for Image Processing and Video Prediction, Neuromorphic Computing Systems and its applications.

Prof. Ahmed Dallal, University of Pittsburgh

Dr. Dallal is an assistant professor at the department of electrical and computer engineering, Unversity of Pittsburgh, since August 2017. Dr. Dallal primary focus is on education development and innovation. His research interests include biomedical signal processing, biomedical image analysis, and computer vision, as well as machine learning, networked control systems, and human-machine learning.

©American Society for Engineering Education, 2021

Teaching and Managing Remote Lab-based Courses

Abstract

In response to the COVID-19 pandemic, instructors and students were asked to carry on with online learning during the shutdown as of mid-March 2020. Emergency remote laboratory classes had to replace the in-person labs, which left the instructors with too many adaptations to do, in very short time. Instructors of lab courses had to convert all the contents to online platforms. Moreover, they had to assemble lab kits and mail them to the students' homes. Students were also new to the remote-learning experience, let alone the experience of having laboratory sessions at their homes. In this article, the experience of two lab instructors with transforming four lab courses to remote format is presented. The specifics of the labs' setup procedures are discussed, along with the pros and cons of the applied methods. A survey-based study is included to reveal the students' opinions about the remote labs, and their suggestions for improving the process. The viability of remote labs replacing traditional in-person labs will be debated.

1. Introduction

As all schools around the world reverted to remote learning early in 2020, most STEM programs have suffered greatly. These programs flourish, and are made distinct, by the ability to conduct laboratory classes. The absence of the latter deprives the STEM programs from their main distinction from other literary programs [1]. It has been reported that "COVID-19 has placed universities in a no-win position. If they implement remote instruction as a substitute for the in-person classes traditionally offered, complaints about the quality of instruction are inevitable. However, if they bring students back to campus, they face the risk that COVID-19 infections can escalate rapidly" [2]. It became no surprise that there was a number of lawsuits against schools, especially engineering schools for not lowering their tuition fees while not offering in-person classes [3]. From engineering students' perspective, those in a traditional, non-distant learning-based program, a hands-on experience is expected mostly through laboratory classes [4-6]. They usually enjoy laboratory classes and look forward to implementing what they had learnt in book courses. But most importantly, since project/lab-based learning is one of the most effective and better resonating methods of learning, and one that distinguishes between engineering programs [5, 6]; engineering students immediately feel that they are getting their money's worth when engaging in a laboratory environment.

Different engineering schools struggled to convince their students with "emergency" remote laboratory classes as an alternative to in-person laboratory classes [7, 8]. As ABET has not relaxed any accreditation requirements, it was mandated that laboratories carry out remotely with minimal compromise to the hands-on experience. Thus, it became the instructors' obligation to setup remote labs at every student's home on their rosters.

In this paper, two instructors' experience of setting up four remote hardware and software labs is presented. We discuss in detail the advantages and caveats of the process. The job of assembling and mailing-out laboratory kits to classes, where over 40 students have enrolled in, have proved to be a challenging endeavor. This hurdle was overcome with perseverance from the instructors, administrators and sales support teams at vendors and suppliers. The instructors further faced problems related to remote lab handling such as managing teams working remotely, difficulty of remote-debugging software and hardware experiments, lab kits faults, and providing support for software installation. Students have complained about communication challenges in a remote lab environment between students of the same team, different teams of students, and between students and the lab instructors. Other remote lecturing problems like internet issues during conducting lab-meetings, and students being at different time zones were also intrinsic of the remote learning process.

The classroom dynamics of both in-person laboratories and remote laboratories are compared in section four. In the fifth section of this article, a survey-based study is reported. The surveys were conducted to gage the level of satisfaction of students, along with the depth to which the lab materials resonated with students in comparison to in-person labs. An assessment is made in section six, to reveal how remote teaching may compromise the quality of the laboratory experience and how well the learnings will resonate with the students. The viability of remote laboratory classes as alternatives to in-person laboratories is discussed.

2. Remote Laboratories Setup Logistics

In this study, a total of four lab courses are established remotely in students' homes. Two sophomore-level lab courses, comprising an electronic circuits lab and a microcontroller interfacing lab, are included. One sophomore-level C++ programming course, and a junior/senior level electronic circuits design course are included as well.

2.1 Hardware lab kits

The parts list for the hardware kits was updated to account for all the needed components, as some of the parts in the previous kits depended on the students being physically present at the labs and capable to pick up components. The kit was assembled to be sent to students at their homes. Firstly, the students enrolled in the lab courses were asked to provide their mailing addresses via Qualtrics® surveys administered three weeks, before the semester commenced. Of course, the rosters for the lab classes have not been finalized then, but the initial list of addresses obtained gave the instructors an approximate estimate of the number of kits needed, and an estimate for the cost of the kits.

While different hardware kit assembly methods have been attempted; the easiest method was getting a supplier to assemble and mail out the kits to the students. This has incurred some delays like third party supplier lead-times for some components, and time to survey the students for mailing addresses. Moreover, some components had to ship from overseas and incurred more delays during the pandemic. Those international components were replaced with ones, usually more expensive, from local suppliers to address the urgency of timely kit assembly and distribution. The assembly was also subject to human error, where some kits were missing some components. Provisions were made to allow for extra parts and components were ordered to the instructors' homes, so when a student reports a missing, or damaged component, the instructor would quickly mail-out a replacement.

For an electronic circuit design remote lab, the ADALM2000® kit replaced the need for separate equipment as it is an all-in-one oscilloscope, function generator, power supply, voltmeter, spectrum analyzer, and network analyzer. The latter two features are very useful in determining the frequency characteristics of amplifiers and filters. Similarly, the ADALM1000® kit was provided for a less advanced electronics lab, which has lower features to the ADALM2000®, like the lack of frequency analyzer, but costs quite reasonably for an introductory-level lab course. The kit provides power railings of +5 /-5 V which is safe for operation at home and in absence of an instructor physically observing the laboratory. Nevertheless, the safety instructions were tailored to the new home labs.

The students were asked to handle the components with care, in absence of physical instruction, and were told that some of those components must be returned by the end of the semester. Most students have been able to physically hand back the equipment in a very good condition, at a booth set outside the school building, maintaining proper COVID-19 regulations for social interactions. Those who could not show up to the kit drop-off in-person, have mailed there kits back and were reimbursed for the mailing costs. The returned kits were thoroughly checked by the instructors and have been set aside to be reused in the lab courses offered in the subsequent semesters.

2.2. Software licensing and installation

The instructors needed to provide the licenses for the software packages for PSPICE labs, microcontroller labs, and software programming labs. Some academic software packages were available for free to students, like the OrCAD® for electronics circuit design and implementation. The instructors needed to contact the developer to expedite and facilitate the licensing and installation processes. Also, several software packages were needed to operate the hardware kits, e.g., microcontroller development kits KEIL® for microcontrollers labs, or Scopy® and ALICE® software suites for the ADALM2000® and the ADALM1000®, respectively.

Open-source programs were also alternatively available to students, especially for students who use operating systems other than Microsoft® Windows on their computers. For example, in the electronics lab, LTspice® was used by students who were using Apple®-MacOS, because OrCAD® only works on Microsoft® Windows. Virtual machine licenses were also provided for students in cases of failure of installation on an operating system other than Windows®, but it is important to warn here that some licensed programs, like OrCAD®, will not permit use on a virtual machine. For a C++ programing lab, the students found it relatively easy to download and install open-source IDE like Geany® on any operating system.

Establishing software-based labs proved to be a tiresome endeavor, again dealing with many students with different computer skills and different operating systems. It is imperative to remind the reader here, that the instructors did not have the leisure of enforcing computing system requirements on the students enrolled in the courses. Thus, it was the mission of instructors to make sure that labs work on the existing computers that the students owned or borrowed.

2.3 Remote labs delivery and dynamics

The remote lab sessions were conducted on Zoom®, where the instructors met with students in the main room for a short lecture on the experiment, then the students' teams were sent to preassigned breakout rooms to carry out the lab experiments. This was the delivery method chosen for three of the four lab courses in this study, and the fourth remote lab (C++ programming) deployed a flipped pedagogy. In the flipped class, the students would view the recorded lab instructions prior to the remote lab sessions, then engage the instructors and team-mates during class time implementing the experiment in teams [9, 10]. Each team of students comprised two students who were responsible of carrying of the lab experiments together and deliver all deliverables, similar to the in-person labs. The students could ask for the instructor's assistance in the breakout room when needed. This system worked well, albeit for when the instructors are needed in multiple rooms at the same time, that resulted in long wait times.

The classroom dynamics of both in-person laboratories and remote laboratories are clearly different. While students are allowed to interact freely with their classmates and instructors in a physical classroom, a remote lab firmly separates the students and blocks communication channels between different teams. Moreover, simply by being in a lab, a team of students can gage the level of advancement or progress in a certain experiment compared to other teams. They can listen to instructions or tips given to another group, and make note of them, without having the instructors visit with and talk separately to each group. In remote labs, the instructors suffered from going back and forth, between breakout rooms tending to various teams, often repeating the instructions.

3. Students' perception of remote labs

Ninety-nine students in four lab-based courses were surveyed about the remote labs. The students were asked to volunteer to complete the survey presented on Qualtrics®. Human subjects' approval (PRO18060710) was secured for these various forms of assessment. The survey questions are shown in Table 1; firstly, asking the students about the issues they have faced when setting up the remote labs at their homes. The second, and third, survey questions were devised to gage the level of satisfaction towards remote labs and inquire about their preferences regarding remote or in-person labs, respectively. In the last question in table 1, the students were asked to provide feedback on any substandard or missing aspects in their remote lab experience. An additional space was provided for the students to provide any feedback, unaccounted for in the survey questions, or if they had any remarks or comments.

3.1. Problems in remote labs setup

Out of 99 responses, only 19 students did not complain about the remote lab setup. The majority of the students have faced some problems as shown in Fig. 1. Problems with the software download and installation on different operating systems were the major complaint in remote labs. The use of hardware components was the second major source of concern, as students struggled to learn the handling of new equipment without physical instruction. Fifteen students have indicated that they received the kits either late, or with missing components. Approximately 7% of the responses reported the receipt of defective hardware components in their kits.

The students' responses to the surveys also indicated some shortcomings that are inherent to remote learning. Approximately 19% of the students have complained that there were problems with the internet bandwidths that caused regular nuisance to the remote lab flow. Those students would often get disconnected, or the Zoom® program would crash, and would require reconnection and reassignment to the breakout room. Three percent of the surveyed students reported difficulties in tuning into live labs to work with their lab partners, while residing at different time zones.

Table 1. Part of the survey questions related to remote labs.

Did you have any issues working on the remote labs? Choose all that apply.	○ I have experienced problems working with hardware ○ I have experienced problems working with software ○ I have received the lab kits late into the semester, or items were missing ○ Some of the received equipment was defective ○ I have had no issues
How would you rate the remote lab experience?	○ Satisfied ○ Somehow Satisfied ○ Neutral ○ Somehow Unsatisfied ○ Unsatisfied
Judging by your overall experience with the remote labs this summer, which of the following statements best describe your experience.	○ I prefer remote labs to in-person labs ○ I have had no issues I prefer remote labs to in-person labs ○ I would have preferred in-person labs to remote labs ○ If I go back in time, I would defer my enrollment in the lab course until in-person labs are resumed
Which aspect(s) do think was(were) missing or can be improved in the remote labs this summer?	○ Good communication with your team members ○ Good communication with other teams ○ Good communication with the instructors ○ Hardware implementation and debugging ○ Software installation, use and debugging ○ Nothing was missing or can be improved

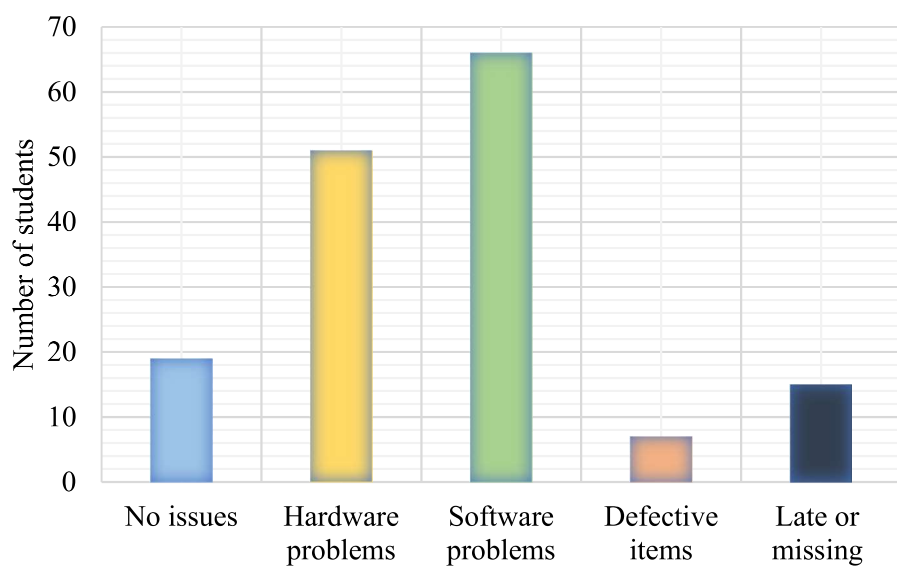

Figure 1. Problems reported by students as they setup remote labs in their homes.

3.2. Gaging the levels of student satisfaction with remote labs

When the 99 students were asked to express the level of satisfaction to the remote lab experience, 36% were satisfied or somehow satisfied by the experience, 16% were neutral and 48% were either partially or completely dissatisfied. Figure 2-a illustrates the satisfaction levels of the students with the remote labs. When the data for separate lab courses were revised, it was apparent that that for three courses the satisfied students exceeded the none satisfied students by a ratio of 1.3:1. However, the sophomore electronics lab course had a ratio of 5.5 dissatisfied students to each satisfied student. This remote lab was run mainly by teaching assistants, who were fairly inexperienced with remote teaching methods, that compromised the satisfaction readings from the 29 students attending that remote lab. The feedback from the students provided in the remarks section showed a ubiquitous complaint from most students about the remote instruction, more than any other aspect of the remote lab. This proved the previous inference that the teaching assistants needed more detailed training to apply remote learning techniques.

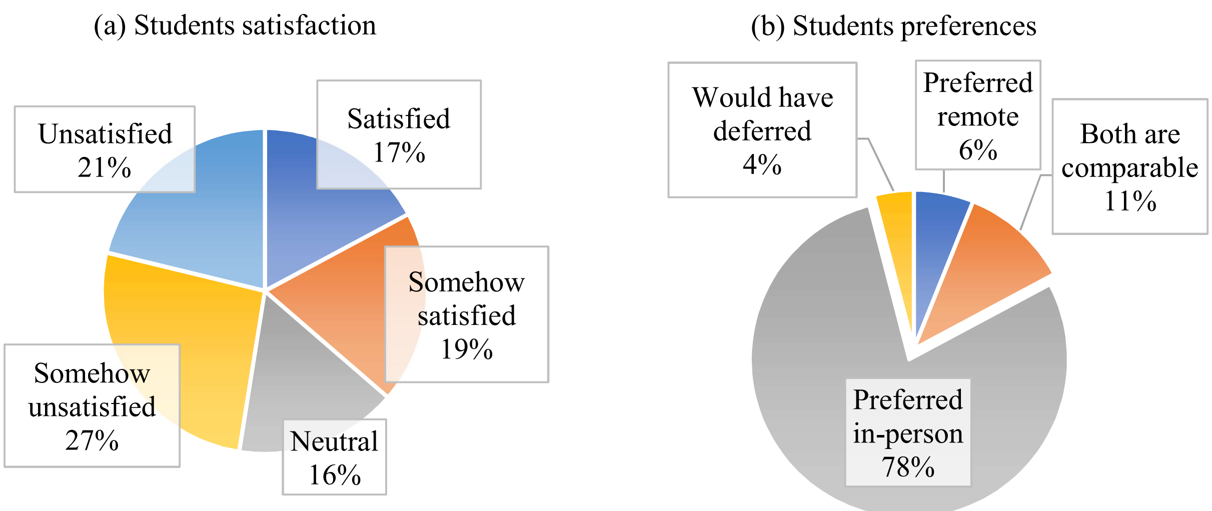

Figure 2. Statistics from questions two and three of the survey a) students satisfaction levels towards remote labs, and b) students' preferences after experiencing the remote labs.

3.3. Students' preferences: In-person vs. Remote labs

As shown in Fig. 2-b, the survey results clearly show that students prefer in-person laboratories to remote ones. Seventy-eight students favored the in-person labs, while only six preferred the remote-lab experience. Eleven students were unbiased to either lab styles. However, most students were determined to continue with their study plans, undeterred by the pandemic, as only four students had expressed their desire to have deferred the labs until in-person labs are resumed.

3.4. Student's feedback and suggestions

In the last survey question, the students were asked to provide suggestions on which aspects of the remote labs need to be improved. Figure 3 illustrates the students' responses to that question. Fifty-five students have expressed that more resources and support for software installation and debugging is needed. Comparably, 53 students have asked to improve the guidelines for hardware handling and debugging.

Communication problems were also a major source of concern that the students voiced in their responses. Approximately, 56% of the students indicated that there were some difficulties instructor-student communications. That was mainly due to the delays that happened when one-team requested to meet with the instructor while the instructor was assisting another team in a different breakout room. Inter-team communication needed to be improved according to 42% of the students, while 32% of the students have reported that intra-team communications need be improved in the remote lab classes.

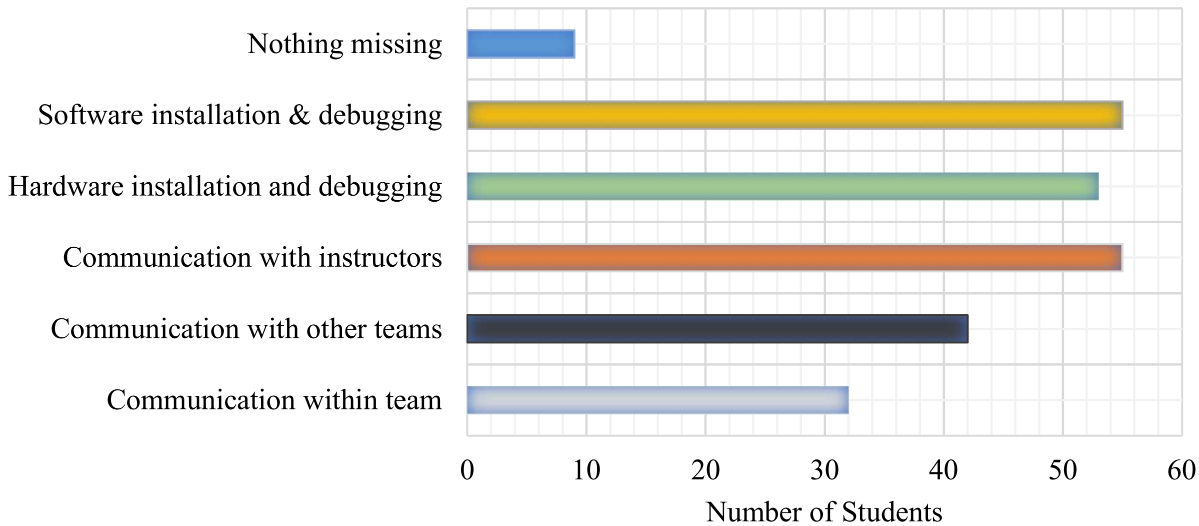

Figure 3. Student feedback on weaknesses in the remote labs.

3.5. Students' performances in remote labs to in-person labs

To assess the student performance in a remote lab setup, we compare the test scores from a C++ programing lab during the spring of 2020, where the students have experienced both in-person and remote instructions in the same semester. This lab course, as mentioned before, was the easiest and fastest to convert to a remote format, as most students have had the compilers already installed on their machines prior to pandemic shut down. Table 2 summarizes the results from comparing their test results, where Exam 1 was given to the students before shutdown, and in a classroom, while Exam 2 was administered after the students had worked remotely from their homes, for six weeks. Both exams had a similar level of difficulty, and each exam covered a separate part of the course content. In Fig. 4, the results from comparing the two tests show that the students performed comparably on both exams, which is a good testament to the remote labs. The comparison between students' performance in two exams were done using paired samples *t*-tests as well as Glass's delta effect sizes. The Glass's delta effect size was calculated to determine the practical significance of the differences, with values below 0.50 considered small, and values at 0.80, or above, large. In addition, the non-parametric samples Wilcoxon signed-rank test was run to corroborate the results of the *t*-test given the small sample size ($N = 31$). Both paired tests, as shown in table 2, indicate no significant difference found between the two scores, with a small effect of the sample size.

Table 2. A summary of the statistics of the exam scores for the C++ programming lab (N= 31).

Mean Score		***p***		**Effect Size**
Pre-pandemic	Post-pandemic	Paired samples *t*-test (parametric)	Wilcoxon signed rank test (non-parametric)	Glass's delta
77.61	74.38	0.261	0.299	-0.18

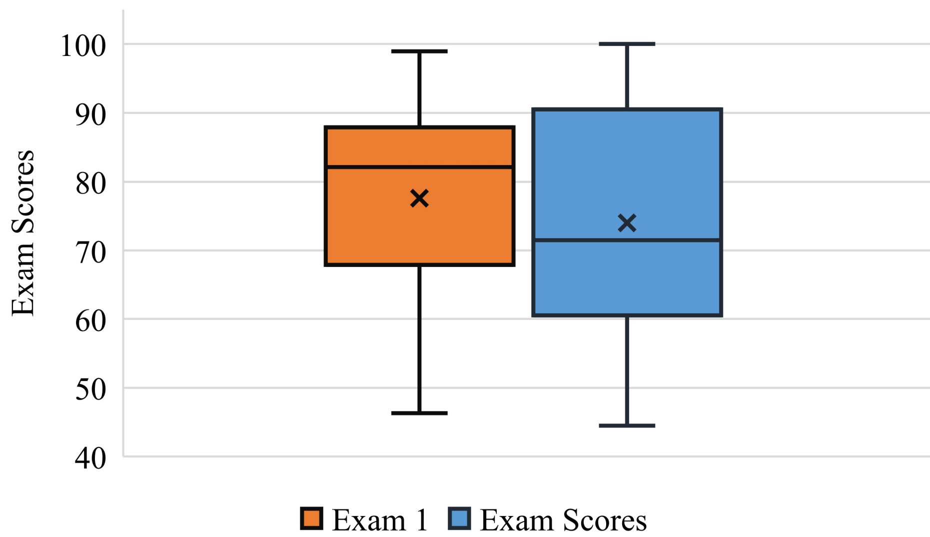

Figure 4. The exams score compared for the in-person test (Exam 1) and remote test (Exam 2).

The test results from the programming course are presented here as the testing methods were the same for both in-person and remote labs. For the other lab courses in this study, the transition to remote platform changed the testing method considerably, therefore comparing the test results for the same group of students in an in-person and a remote lab setting will not be reliable."

4. Discussions and Conclusions

The current job market constantly demands the engineering graduates be well trained in practical aspects of engineering [5]. No matter how much instructors seems sceptic of remote learning [11], instructors must not abandon hands-on lab training, even during the pandemic. Nevertheless, setting up and installation of the remote hardware and software labs have been a challenging endeavor. The surveys showed that those were the main causes of dissatisfaction among the students. The instructors further faced problems related to remote lab handling such as managing teams working remotely, difficulty of remote-debugging of software and hardware experiments, and lab kits faults.

While the responses to the four survey questions showed a great deal of dissatisfaction among the surveyed students, most students have expressed their gratitude to the instructors for conducting remote labs at the times of the pandemic, and for exerting noticeable effort to establish the remote labs at students' homes. One student remarked: "I imagine that it has been difficult to transition labs to an online setting, but this class has done pretty well." Another student had commented: "Not all bad. The instructor and the TA were excellent at what they did given the circumstances." Some students have recorded that they prefer the new take-home lab kit, "The lab equipment was effective. The scope was surprisingly helpful and would actually prefer to use the ADALM2000 even when back at the labs because it offers simple controls and because it has a lot of built-in features."

The classroom dynamics of both in-person laboratories and remote laboratories are clearly different. Evidently, in-person presence in a laboratory, allowed students to voice their concerns easily to the instructors, and inquire about the issues they struggle with promptly. In a remote lab with only two instructors, the instructors struggled to cater for multiple breakout rooms at the same time. To deal with the communications problem in a remote lab, more interactive activities must be devised for students to form bonds with team-members, most of whom they have not physically met before. A student testament clearly shows the advantage of in-person interactions to remote ones: "I felt like I had an easy time with the labs because I'm roommates with my lab partner. We were able to use both our kits to have more components." A recommendation is made here for instructors of a remote lab to encourage students to often visit other breakout rooms, to promote discussions between various student teams.

In conclusion, the remote labs are viable, and has addressed the urgent need for hands-on experience during the pandemic, however, it would take some time for both instructors to master remote-lab teaching, and for students to adapt fully to effective remote labs practices. The test results from one programming course in this study were very similar for both in-person and remote labs, which suggests that the quality of the laboratory experience has not been compromised for that course, and the learnings have resonated well with the students. However, for other hardware-based lab courses, the testing methods vary between in-person and remote labs, so were not indicative to the difference in quality of the student gains between in-person and remote labs. The authors recommend that the students carry on with their study plans, with remote labs as alternative to in-person labs, for this study has shown that it may not be a popular alternative, but still an effective one to achieve course learning objectives. Careful planning of the "emergency" remote labs setup and execution can eventually make them popular and may one day replace the in-person labs.

References

[1] D. Coker, "The Canary in the Mine: Remote Learning in the Time of COVID-19," *Journal of Curriculum and Teaching,* vol. 9, no. 3, pp. 76-87, 2020.

[2] H. E. s. l. department, "Education and Litigation Alert: COVID-19 Lawsuits against Colleges for Opening or Closing during the Pandemic."

[3] K. Davis, "Student lawsuits asking for COVID-19 refunds pile up against universities," *The San Diego Union-Tribune*.

[4] L. D. Feisel and A. J. Rosa, "The role of the laboratory in undergraduate engineering education," *Journal of engineering Education,* vol. 94, no. 1, pp. 121-130, 2005.

[5] G. Ragusa and J. E. Moore II, "Common denominators of learning," *ASEE Prism,* vol. 26, no. 1, p. 68, 2016.

[6] D. Pusca, R. J. Bowers, and D. O. Northwood, "Hands-on experiences in engineering classes: the need, the implementation and the results," *World Trans. on Engng. and Technol. Educ,* vol. 15, no. 1, pp. 12-18, 2017.

[7] C. Hodges, S. Moore, B. Lockee, T. Trust, and A. Bond, "The difference between emergency remote teaching and online learning," *Educause review,* vol. 27, pp. 1-12, 2020.

[8] M. Assunção Flores and M. Gago, "Teacher education in times of COVID-19 pandemic in Portugal: national, institutional and pedagogical responses," *Journal of Education for Teaching,* vol. 46, no. 4, pp. 507-516, 2020.

[9] A. Dallal and R. M. Clark, "Progressive Use of Active Learning in Electrical Engineering Courses," in *ASEE Annual Conference & Exposition*, 2019.

[10] A. Dallal, A. Dukes, and R. M. Clark, "Student performance in partially flipped ECE laboratory classes," in *ASEE Annual Conference and Exposition*, June 2020.

[11] T. D. Hobbs and L. Hawkins, "The results are in for remote learning: It didn't work," *Wall Street Journal,* vol. 5, 2020.