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Measuring Online Engineering Laboratory Satisfaction During COVID-19 Pandemic

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Abstract : The idea of remote/virtual laboratories is still limited in Engineering due to the nature of engineering applications, equipment, and the competencies students are expected to gain as future engineers. Once COVID-19 hit, there was no time to think, review, and study how educational institutions can integrate remote/distance learning laboratories into their curriculum. Universities in our country and the rest of educational institutions around the globe rushed to find solutions to make sure students still get the best learning experience and gain the core concepts as expected. Many had to make instant decisions and purchase software, simulators, and/or record technical experiments and share them with students. In many majors, this wasn't an issue and there were many resources accessible to students that required minimal direction from educators. However, for engineering majors, simulators are not available for all labs and even if they are available, educational institutions are required to provide them to students with suitable documentation and usage instructions. In addition, recording a demonstration for experiments doesn't provide students with the hands-on experience they are aiming for. Adopt and learn was the main theme during the COVID-19 pandemic. This is what our department did to guarantee a quality lab experience for its students and later communicate valuable feedback to achieve the best level of learning. This paper focused on getting an insight into the lab experience for students in Digital Communications and Analog Communications laboratories during the COVID pandemic. Measuring the satisfaction level of students' experience was via conducting surveys with a focus on three main skills which are: hands-on experience, teamwork, and communication skills.

Keywords: Engineering Education; Online Laboratories; COVID-19; Electrical Engineering.

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1. Introduction

The teaching style in engineering disciplines is unique due to the significant role laboratory experience plays in students' long-term learning. Thus, crafting online/remote laboratories requires much effort to develop and design experiments that cover the core concepts and give students a glimpse of the hands-on experience they need in their future careers. Not to forget the non-academic aspect of face-to-face laboratory experience such as communication and teamwork which play a key role in engineering fields.

Applying the main theories taught in the classroom to real-world applications and finding solutions is what distinguishes engineering education from other science disciplines [1]. To enable students to transform the classroom theoretical knowledge into a real-world experience and provide them with collaborative hands-on experience, educational institutions provide a physical laboratory infrastructure in terms of equipment, tools, and well-designed experiments demonstrated by qualified instructors. Nevertheless, physical laboratories have drawbacks in terms of equipment and staffing requirements [2]. Virtual, blended, or simulated laboratories come into the picture as a solution to this limitation. They have been increasingly offered and evaluated by many engineering programs as communication technology and automation advance and become more available to students [3]. Flexibility, and spending enough time with the lab simulator to understand the flow of the experiment without dealing with environmental issues were the major advantages students experienced in virtual/remote laboratories [3, 4].

Throughout the years, many efforts were focused on online teaching in engineering disciplines. However, engineering majors are still lagging compared to other disciplines [1, 2, 5], especially when it comes to laboratory experience. Laboratory hands-on experience plays a significant role in engineering students' learning. Engineering laboratories are fully equipped with the tools, simulators and devices students need to get a glimpse of the practical part of their core classes and what their future careers might be. Not only this, but a major part of the skillset engineering students need is gained through their laboratory experience such as communication skills, teamwork, problem-solving and more others as they interact directly with their peers, laboratory equipment, and instructors (Budai & Kuczmann, 2018). Not to forget the lack of solid infrastructure simulators or remote laboratories for some engineering courses. Thus, the idea of online or virtual laboratories is not popular in electrical engineering courses as in other majors and some research showed that combining both physical and remote laboratories to equip students with the knowledge and skills, they need has a major impact on students' learning outcomes [6].

Some laboratories were already prepared to switch gears to virtual learning and give students the experience they were looking for. In [7] it was stated that educational institutions had to switch to online/remote teaching due to the pandemic and even though simulators or online labs were functioning, it was an obstacle to adapting to a working strategy that are students student-centered. Face-to-face interaction, one-on-one attention as well as debugging remotely, were the major difficulties students went through during the online lab in electrical circuits course at UC Davis [7]. These difficulties brought attention to the urgent need for new methodologies to utilize students' self-learning skills by offering bonuses for students who volunteered to assist their peers. Since the idea of virtual labs was not new, one study [8] developed an online lab that addresses current existing remote labs' limitations in terms of student interaction and communication. The study highlighted that the remote lab experience improved students' learning opportunities as students were able to interact longer time with the lab equipment.

Another study focused on five major skills students expected to gain from their lab experience: "collaboration, communication, problem-solving, critical thinking, and creativity" [9]. The IoT Rapid Proto lab was designed based on three major principles as follows: "1) Realistic, complex task situations, 2) Multidisciplinary, and 3) Social interaction". It was a combination of traditional in-person lab experience as well as the virtual lab. The article concluded that preparing a solid infrastructure for a blended lab had a great impact on improving students' competencies and the technical knowledge they need for the labor market.

In [10, 11, 12] it was claimed that distance education and online learning approaches are more effective in developing countries with their limited lab equipment resources and qualified instructors compared to the number of students in some institutions. However, there are still obstacles non-traditional students and disadvantaged learners face in the open remote learning environment [10, 13, 14].

2. Methodology

Our institution is considered a large private university in our country with approximately 5900 students enrolled in 27 different majors and coming from 53 different countries. About 800 students majoring in Engineering.

Switching to fully online teaching wasn't an option as in all other educational institutions during the pandemic. In March 2020, the whole country had to close completely due to the COVID-19 pandemic. With the lack of planning and the absence of a systematic way of transitioning to online learning, the instructors and lab Teaching Assistants (TAs) had to develop a methodology that work for the student body, especially with the large number of students coming from different countries and had to travel back to be with their families. At the Electrical Engineering/Communication and Computer Engineering department, instructors as well as lab TAs started recording lectures and tutorials instantly and made the material available to students with the proper instructions to avoid any lagging in student learning. It was unclear when colleges will re-open for students and there was an urgent need to act and utilize all resources available at the moment.

For some courses such as programming, transitioning to remote teaching was easier with the availability of online simulators/compilers. In addition, particular hands-on experience competencies were addressed by assigning groups and having synchronous or asynchronous discussions. With few limitations regarding the student environment and internet resources, the lab experience went well with few adjustments to meet students' learning outcomes.

The biggest obstacle was for laboratories that require direct interaction with equipment and taking instant measures. Having an online meeting was a guarantee for students to gain the theoretical knowledge they are expected to gain but not the practical experience, especially when students have no previous experience in conducting online experiments. In the Electrical Engineering/Communication and Computer Engineering department, many were unable to see the exact measurements and understand how to start using some basic lab equipment which might reflect negatively on their experience as future engineers in the field.

In this paper, the online experience of participants in the Digital Communications and Analog Communications laboratories in the academic year 2020-2021 was analyzed in terms of students' and instructors' experiences. The study participants are 31 students who were enrolled in either the Digital Communications or Analog Communications lab during their junior year, between the ages of 19 and 21. All students in either the Digital Communications or Analog Communications laboratories should have passed the Digital Communications or Analog Communications courses covering the theoretical part before enrolling in the lab to learn the practical part. Participants were asked to answer eight yes/no and open-ended questions anonymously reflecting on their online experience and how it is comparable with current or previous in-person laboratory experience. The survey questionnaire is included in Appendix A. Some students selected neither "yes" nor "no" thus, their answer was put under "neutral" or "no difference".

The department started offering the TutorTIMS software in the Spring of 2021 for both, Digital communication (required for Electrical Engineering/Communication and Computer engineering students) and Analog communication laboratories (required for Electrical Engineering - Power and Control students). Both laboratories were offered online once the pandemic started, and they were both recorded. The survey participants either enrolled in the Analog Communications laboratory in the Fall of 2020 or in the Digital Communications laboratory in the Spring of 2020. The lab instructor goes through the experiment details at the beginning of each lab and reviews the required theoretical part with all students at once before students start working on their experiments. This is the same whether the instructor is in the lab or joining the online meeting. The TA usually assists the lab instructor by following up with students, individually or in groups, and making sure they are all on the same page. Not only this but also make sure they all have the equipment they need, and their tool setup is done properly. During the online lab sessions, the TA's responsibility comes in facilitating the meeting, creating separate discussion rooms to assist the instructor to follow up with each group, and making sure students have no technical difficulties and progress smoothly while conducting the experiment.

During the Fall of 2020, the government in our country allowed in-person laboratories for college students for a while before the number of cases increased and the whole country goes back to total lockdown. Thus, only the first two experiments were in person and after two weeks the reset of experiments (8 experiments) in the two labs were conducted online using TIMS. The first two experiments in the analog communication lab were: an examination of the basic

TIMS modules and amplitude modulation and demodulation. The digital communications lab's first two experiments were pulse amplitude modulation and pulse time modulation. The rest of the experiments in the analog communication lab labs covered mainly: single-side modulation and demodulation, angle modulation, and the superheterodyne receiver. The digital communications lab covered: pulse code modulation and demodulation, delta modulation, and demodulation and carrier digital modulated signals.

Some students got a chance to be in the lab and have direct interaction with the lab equipment. Those students were able to better reflect on the quality of the software used in the Digital Communication lab and the real-life experience they had using it.

The survey focused on measuring the satisfaction level of some engineering laboratory experience skills as well as the overall satisfaction of their online experience. the three skills this research focused on were hands-on experience, teamwork, and communication skills.

Digital/Analog Communications Laboratories:

Due to COVID-19 closures and to guarantee the best learning experience for our students, our institution invested in providing Emona TIMS which is a telecommunication and signals & systems software. The software is designed for university students and has the same approach students are expected to follow in an in-person lab. With the user-friendly interface and easy access to modules functionality similar to the actual hardware, students are expected to learn with the same quality as before. In Analog communication and Digital Communications, the lab manual was the same in terms of theories and core concepts of each of the ten experiments covered during the semester.

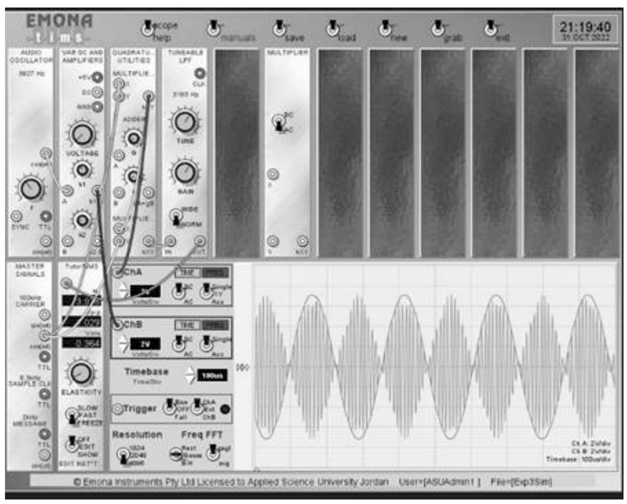
As defined in (About TIMS Telecommunications Training Systems Emona Instruments, 2022) “TIMS is a mathematically-based, engineering modeling system, used to carry out 'hands-on” laboratory experiments in telecommunications theory (transmission theory) as well as Signals & Systems”. The widely used simulator starts with the mathematical equations students need to represent electrical systems. Then, students use block diagrams to build their systems [15].

Results

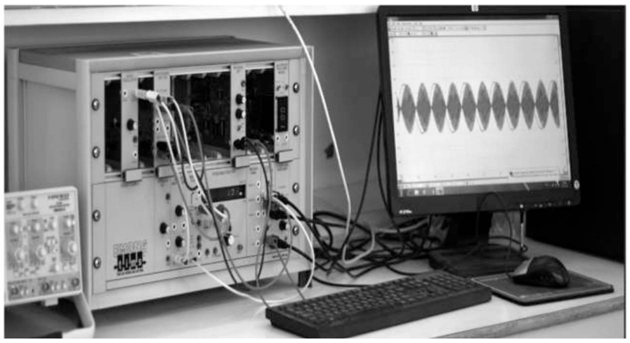
Surveys were administered to 31 students who attended either lab online. Twenty students responded to the survey of which 45% were females. All students were enrolled in at least one of the labs online during the pandemic (Analog communications lab or Digital communications lab). Overall, students expressed that they had a good learning experience online even though they went through some difficulties.

In terms of difficulties and the lab experience throughout the semester, all students agreed that they had a good experience even though it took a long time, in the beginning, to learn to use the tool and conduct experiments effectively. Three students responded that the analog communication lab was still in-person during the Fall/spring of 2020. In the beginning, covid cases were not severe but then due to the increase in cases they started attending the lab virtually, and all experiments were recorded. The students added that the main change was in having assignments instead of manually conducting experiments and writing reports. Thus, there was more focus on the theoretical part.

Unlike when the TutorTims simulator was used in both laboratories. All students enrolled in the digital or analog communication lab mentioned that using TutorTims software was similar to the actual lab but on the computer which gave them a good glimpse of how the actual in-person lab experience would be and maybe better in terms of accuracy and results of some experiments. Fig. 1-A demonstrates the circuit connection of DSB-SC Modulation and Demodulation using TutorTims simulator, while Fig.



(a)



(b)

Fig. 1 : DSB-SC modulation and demodulation connection diagram

1-B shows the connection for the same experiment using the actual lab. The physical setup shown in Fig. 1 was presented to students using recorded video, asynchronously, and not during the lab session for some experiments. It can be noted from the two figures, that the modules are the same and the output for the two systems is the same.

However, one student mentioned that switching to an online simulator was the only option and he still preferred to use the actual lab equipment. Two students had a flexibility issue regarding the limited time to use the TutorTims tool. The tool/simulator would usually open at a fixed time every week to make sure students attend the lab on time. Students prefer to have extra time to work on their experiments if they need to, but this wasn't possible due to the limited license count.

As for the learning quality, students had a good experience with the tool itself and learned the concept well. However, conducting experiments in the lab and focusing on the practical part more than the theoretical part would give them a better understanding of the concept of each experiment.

A. Measuring hands-on experience satisfaction:

Asking students if they would have learned better if they were in the lab and interacting directly with the lab equipment, 60% of students (n=12) answered yes (Table I). Students preferred to be physically in the lab to get a better understanding of the experiment and interact directly with the lab tools and equipment. Students who considered online experiments better referred to the simulation tool used as realistic and sufficient to learn the core concept of each experiment and they had better flexibility to finish the experiment and submit it to their instructor.

Table 1: Measuring Hands-on Experience Satisfaction

Gender	Yes	No	Neutral	Total
Male	7	4	0	11
Female	5	3	1	9
Total	12	7	1	20

B. Measuring Teamwork Satisfaction:

Regarding laboratory experience skills, such as teamwork, students were asked what their virtual teamwork experience was and to mention the main pros and cons they experienced. Most students had no issues communicating remotely with their teammates. As in Table II, 60% (n=12) of students were satisfied and had no issues working as a team during the online laboratory. Students mentioned that due to flexibility they had enough time to help each other share knowledge and get the work done as a team. Some students identified flexibility as being able to meet face-to-face if they were all living in the same city. For other teams, this wasn't an option and they had to rely on Zoom meetings, WhatsApp, E-mail, and Messenger to communicate with their team members and make progress in their assigned tasks.

Table 2: Measuring teamwork satisfaction

Gender	Yes	No	Neutral	Total
Male	7	2	2	11
Female	5	1	3	9
Total	12	3	5	20

C. Measuring communication satisfaction:

Students were asked if they would have communicated better in person than online. Table III shows that 65% (n=13) of students thought they would do better in terms of communicating with their teammates and lab instructors in person. They referred to face-to-face interaction and not having to deal with Back-and-forth communications, asynchronous discussions, and having to take screenshots frequently we the main keywords explaining online teamwork difficulties compared to in-person groups. 20% (n=4) of students considered online communication faster and easier as they get to hear all questions from other students during online lab and learn from them.

Table 3: Measuring Communication Experience

Gender	Yes	No	Neutral	Total
Male	7	2	2	11
Female	6	2	1	9
Total	13	4	3	20

Looking at the responses regarding the major struggles were lack of resources and lack of home environment preparation they had, such as limited home devices and bad internet connection. One student mentioned that she went through the fear of being disconnected every time she logs into a meeting. In addition, working with teammates in different time zones was hard and hence, it took a long time to solve problems and get things done.

Table 4: Measuring overall laboratory satisfaction

Gender	Yes	No	Neutral	Total
Male	6	1	4	11
Female	3	5	1	9
Total	9	6	5	20

Asking students if they would have done better if they were in person, it was noticed that the responses differed between males and females. As seen in the table above (Table V), about 54.5% (n=6) of male students preferred to be in-person and mentioned they would have done better being physically in the lab and learning how to use the actual tool and lab equipment. For those who responded with "no" or "no difference", their responses focused on the quality of the simulator used in the lab and how close it was to the actual lab tools. In addition, flexibility and learning as a team had a great impact on their online experience. As for female students, 6 out of 9 students responded with a "no" or "no difference". Similar to their male counterparts, the realistic simulator, accurate results, and flexibility in submitting the assignments were the major factors in preferring online laboratories.

3. Discussion

EMONA TIMS simulator was designed for university students to mimic the actual telecommunication labs' theoretical and practical experience. Students had no issues learning how to use it with minimal directions and were able to implement the lab experiments effectively as if they were actually in the lab. The software is designed to allow students to follow the experiment tutorial easily from anywhere. Regardless of the lack of recorded instructions provided by the lab instructors at the beginning of the pandemic, students were able to ramp up quickly and implement their experiments effectively. Not only this but also there were no major changes to the lab manual which allowed students to stay on schedule with the lab experiments without any dependencies or delays.

In engineering, applying the theoretical part isn't the only intention of integrating labs into the curriculum. Students are expected to develop their teamwork skills, communication skills, and hands-on experience to be ready for the actual work. Virtual labs are critical and might fail in developing any of the non-theoretical sides if it wasn't designed adequately. For this study and as seen in Fig. 2, students were satisfied with their teamwork experience. In the beginning, it was hard for some students to communicate with their teammates, but it got easier later. Students were able to work together smoothly and help each other to get the work done.

However, technical difficulties and limited communication resources were an issue for some students especially when there are multiple students in the household sharing limited devices with a poor internet connection for some students.

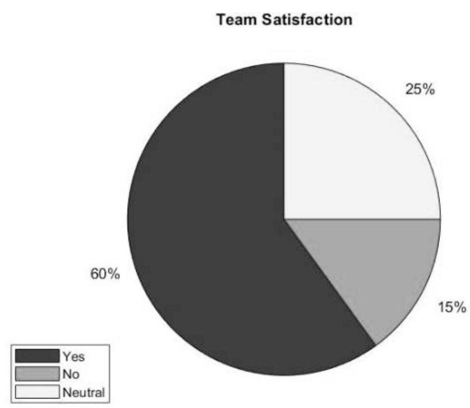


Fig. 2 : Team-Work Satisfaction Measure

As for communication skills, 65% of students preferred face-to-face communication as in fig. 3. Flexibility in submitting assignments made it easier to get things done but one-third of the students responded that it took longer to interact back and forth with teammates until a specific issue is resolved. Similar issues can be avoided if they were in person as they can communicate faster and get instant help from the lab instructors. In addition, most students prefer to interact directly with their instructor, they were available and answered students' questions quickly which made students more comfortable asking questions. This issue can diminish over time as students get used to communicating remotely with their instructors and teammates.

The environment and at-home setup were not covered in this research. Not all students had the same

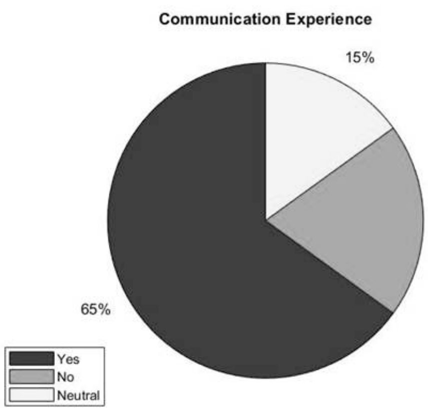


Fig. 3 : Communication Experience Measure

setup during the pandemic which might have affected their remote learning experience. Another limitation was not collecting data from instructors' perspectives which could give us a deeper insight into the barriers and solutions regarding integrating remote laboratories into the curriculum.

The analog/digital communication lab students felt more comfortable when they worked on a well-structured simulator that reflected what they expected in the actual lab environment. The ramp-up time was reasonable as the training material was well-designed and available. However, students' experience wasn't the same in the analog communication lab when it relied on recording the theoretical part and experiment instructions. Online or hybrid learning needs to reflect the actual hands-on experience and have students learn a new tool that can be useful in their future careers.

The overall satisfaction between male and female students was different. Five out of nine female students preferred to be online with their online experience compared to six out of 11 male students who preferred to be in person and interact directly with the lab equipment. This difference could be due to the cultural background as female students are a minority in engineering and they don't feel comfortable working closely with their male teammates. These cultural differences need to be investigated to highlight the reasons and find solutions as needed.

Overall, students felt more comfortable being in the laboratory, asking questions, learning from mistakes, and interacting with their teammates and instructors. Students had a good online experience due to the high quality of the simulator used and the flexibility in submitting their laboratory reports and assignments. In addition, being able to learn as a team and help each other outside the laboratory hours had a positive impact on students' online experience. However, many students still prefer applying the theoretical part of the lab using actual machines and communicating face-to-face with their teammates and instructors. Thus, in engineering, having laboratories designed in hybrid should suit all students. The flexibility this setup brings will improve students' learning process and success.

4. Conclusion

In conclusion, using a well-defined simulator/tool is a key player in the remote/hybrid learning experience. While students may encounter initial challenges, they tend to adapt and benefit from the flexibility offered.

Regardless of the flexibility students had in terms of conducting the experiment and submitting the lab reports, they still prefer to be in person and interact with the lab instructors, teams, as well as lab equipment. Thus, a hybrid laboratory model with flexible hours emerges as the best solution. Using this approach will provide students with both theoretical knowledge and hands-on experience, as well as equip them with essential skills for their future careers.

By incorporating a hybrid learning model, educational institutions can still create an effective learning environment as well as enhance their experiment design and train their students to use the latest tools/software available in their fields.

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