Faculty Adoption Over Time to Online Laboratories in Electrical and Computer Engineering Classes Throughout COVID-19

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***Abstract*— This work-in-progress innovative practice paper presents research that follows up on a recent paper on faculty perspectives regarding the transition to exclusively online laboratory classes in electrical and computer engineering, which was presented at a conference in 2022. As we gradually moved away from the COVID-19 pandemic, faculty phased back to using in-person labs instead of the online (remote and virtual) laboratories that they had transitioned to in 2020. The data presented in this paper comes from two separate sets of interviews, each lasting 30 to 45 minutes, with five interviews conducted in each set. These interviews were recorded within two years of each other. Similar to the previous paper, we once again apply the diffusion of innovation and the framework of propagation to identify effectiveness and fit as key factors in the successful adoption of innovation. The online labs utilized in this study include the VISIR remote lab, the EMONA remote lab, and the MULTISIM online circuit simulator. The objective of this paper is to explore any mindset changes that faculty members have experienced regarding the adoption of these online laboratories in their classrooms. This paper allows us to gain deeper insight into important aspects related to the integration of online laboratories into our classrooms. Common themes from the first set of five interviews include constant comparison to "real" labs, time flexibility and individualized support, differences in learning outcomes, the necessary connection between lecture and lab, and student engagement with the lab. Preliminary results from the follow-up set of interviews show a similar set of results but with a stronger emphasis on the comfort found in using online labs after a year of use. There is a significant push to use the remote labs in conjunction with the in-person labs or even as a pre-lab. Through this work, we aim to develop an evidence-based understanding using an inductive approach to the data.**

Keywords—virtual laboratory; electrical engineering; educational software

I. Introduction

Online labs have played a key role in continuing laboratory education when physical gathering was not possible during the outbreak of the pandemic in 2020. By online labs, we mean either virtual labs or remote labs. A remote online lab is a real physical infrastructure that can be accessed remotely from any location. However, the entire laboratory infrastructure takes place in the form of a software program accessible over the internet in the case of virtual labs or simulation labs. Amidst the COVID-19 pandemic, educators faced the urgent task of transitioning to online teaching, presenting unique challenges for hands-on laboratory instruction. Even faculty members who were initially skeptical of online experimentation had to adapt. The situation provided a rare opportunity to study factors that influence adoption or resistance to online teaching methods, which are often overlooked in typical circumstances. Previous research on online experimentation has been limited, often neglecting the perspectives of faculty members, who are crucial users.

An online version of the Fundamentals of Circuit Analysis course that incorporated fully online laboratory modules for electrical circuit building provided an opportunity for us to explore faculty experience during the sudden shift to online-based laboratory instruction. We were particularly interested in understanding faculty resistance or acceptance of these technologies. We utilized the creation and implementation of these online labs, along with the integration of online instruction modules, to explore the following research question:

“Do faculty perspectives on the use of online laboratories shift over the course of the pandemic life cycle?”

Drawing on the Diffusion of Innovation Framework [1] and the framework of propagation [2], which emphasize effectiveness and fit as key factors in technology adoption, we are investigating five factors influencing adoption: relative advantage, compatibility, complexity, trialability, and observability. Our research employs a qualitative approach using semi-structured interviews. The focus of our work is on the insights gained from faculty interviews. This framework will contribute to the propagation of educational technology, specifically tailored to the requirements of online laboratory instruction in engineering education, especially now, when the pandemic is over and faculty have started to return back to physical labs.

II. Prior Work

A. Research on Virtual Online Laboratories

Online instructional environments have undergone significant developments to support faculty in delivering their courses remotely since the onset of the COVID-19 pandemic. Among the various types of classes that had to transition, in-person laboratories faced particularly challenging adjustments to enable online access [3-5]. In response to this rapidly evolving landscape, STEM faculty were compelled to utilize remote laboratories (physical equipment operated from a distance), augmented reality labs (real labs enhanced with virtual reality elements), and virtual laboratories (fully software-based labs often utilizing simulations) to maintain the continuity of their classroom activities. Collectively, these approaches are encompassed by the term "online laboratories" [6-11].

Students interact with physical lab content, as is the case with remote labs, or virtually, as is the case with online laboratory environments. Through manipulating these elements and observing their effects, students gain valuable insights into the relationships between different variables within the conceptual framework of online labs [12]. Online labs offer several advantages, including cost efficiency, round-the-clock accessibility, and flexibility, while also facilitating simultaneous access for multiple users. Additionally, they enhance damage resistance, user safety, and accessibility to diverse experimental setups since they do not involve hands-on manipulation of components [13-16]. However, there are also drawbacks, such as the complex development process and a perceived disconnection between real-world and online experiences in terms of user engagement and responsibility [6, 17, 18].

Despite these inevitable challenges, numerous studies have demonstrated the effectiveness of online laboratories in engaging engineering students in practical learning experiences, promoting autonomous learning, and fostering problem-solving skills, ultimately enhancing student motivation [19-21]. However, existing research heavily relies on student perspectives, which may not offer a comprehensive understanding of the effectiveness and efficiency of online labs, particularly regarding learning outcomes [22-26]. Research findings about students' online lab experiences are contradictory across disciplinary boundaries - indicating significant variability in students' online lab experiences across studies and institutions [11]. A notable research gap pertains to the adoption and implementation process of online experimentation from the faculty member's perspective.

B. The Previous Study

As mentioned earlier, this paper serves as a follow-up to a conference paper titled "Faculty Perspectives on Transitioning to Exclusively Online Lab Classes in Electrical and Computer Engineering," published in 2022 [27]. The previous study employed a qualitative analysis using an inductive approach to investigate faculty attitudes toward the mandatory transition to online labs during the COVID-19 pandemic. It involved five faculty members from the electrical and electronics engineering department at the (blinded institution). The virtual lab context centered around the "Fundamentals of Circuit Analysis" course, utilizing two remote labs, VISIR and EMONA, as well as one simulation, MULTISIM. The qualitative analysis revealed preliminary themes, including scheduling flexibility and individualized support, differences in learning outcomes, the connection between lecture and lab, and student engagement with the lab. Additionally, there was an overarching observation that students frequently compared the online labs unfavorably to the in-person labs, as noted by the faculty. This current study delves into the evolution of faculty mindsets and their varying perspectives one year after the original interviews were conducted.

III. Research Design and Methodology

We adopted a predominantly qualitative method involving semi-structured interviews with faculty members To explore the faculty viewpoints within the described context and address the research question. The interview protocol drew inspiration from two main sources: Firstly, we incorporated insights from Froyd's framework of propagation [2], which links fit, efficacy, and the adoption of educational innovation from a faculty perspective. Secondly, we integrated elements from the diffusion of innovation framework [1, 28-30], which outlines key factors influencing technology adoption or rejection, including relative advantage, compatibility, complexity, trialability, and observability.

We conducted ten semi-structured interviews with faculty members from the electrical and computer engineering department at our college, comprising four male and one female participant. Five interviews were conducted in the earlier study, and five interviews were conducted after a one-year gap.

Regarding seniority, the interviewees spanned a range of experience levels, from young faculty with less than three years of teaching experience to seasoned faculty members with over ten years of teaching experience. The first set of five interviews took place from the Summer (one interview) to the Fall (four interviews) of 2020. These are referred to as our F1 through F5 interviews. The interview duration ranged from 30 to 45 minutes. The interviews were transcribed to analyze the data. Over one year after the first set of interviews, the second set of interviews were conducted. Four out of five were the same faculty members, whose views and opinions were asked in the form of semi-structured interviews on the transition from offline to online and what has changed since then, in their opinion, and what they feel in present circumstances. In the next round of interviews, the interviews were conducted in Spring of 2022, when labs were being conducted in a hybrid format. These are referred to as our S1-S5 interviews. The interviews were transcribed, and analysis was carried out using thematic coding by the researchers, using a qualitative analysis software called NVivo. Major and emerging themes were identified.

The online laboratories utilized in this study comprised three distinct educational technologies and types of online laboratories for delivering laboratory-based courses in the field of electrical circuits building online. These included two remote laboratories and one full simulation:

A. The VISIR Remote Lab

The VISIR remote lab workbench features a web interface that allows students to operate familiar benchtop instruments from their computer screens, such as a virtual breadboard, multimeter, and basic electronic components [31]. This setup replicates learning by simulating essential operating functions, including moving components and adjusting instrument settings. Similar to a physical lab environment, students interact with the virtual user interface on their computer screens, while the connected experimentation unit provides real experiment values.

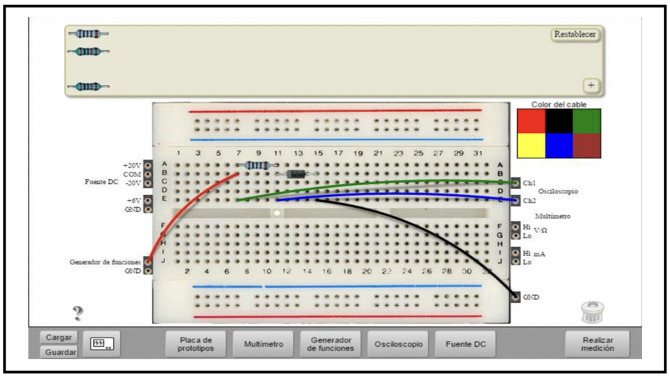

Figure 1: VISIR remote lab user interface

B. The EMONA Remote Lab

The Emona TIMS netCIRCUITlabs offers online access to multiple students simultaneously for controlling and measuring real electronics circuits. Accessible via a web browser, the system encompasses various experiments, including AC amplifiers, feedback circuits, and differential amplifiers. The lab equipment comprises a control unit and several switchable boards for different experiments [32]. As with VISIR, students interact with the user interface to engage with the equipment, while experimentation data is generated using real equipment.

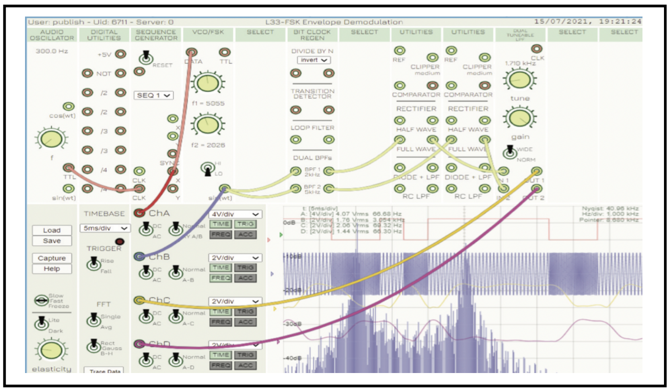

Figure 2: EMONA remote lab interface

C. MULTISIM Online Circuits Simulator

The third online lab utilized by faculty for delivering lab courses online was Multisim, an electronic schematic capture and simulation program developed by National Instruments (NI). This program provides an advanced, industry-standard SPICE simulation environment for circuits building and is widely used in academia and industry [33]. Unlike the aforementioned labs, MULTISIM is purely simulation-based and is not connected to any physical equipment during the experimentation process.

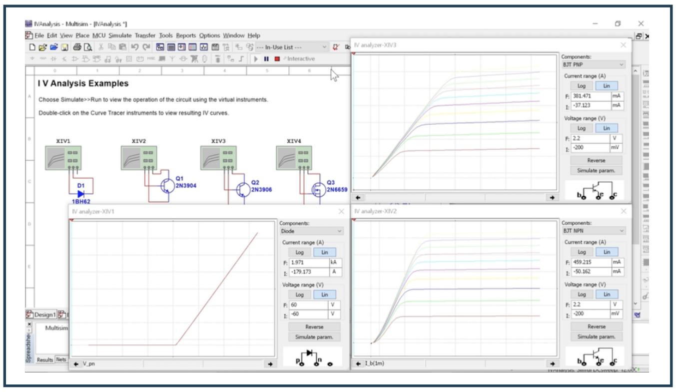

Figure 3: MULTISIM user interface

IV. Results and Analysis

A. Reiterated Themes

1. Scheduling Flexibility and Individualized Support

The most commonly mentioned advantage of the online laboratories from the F1-F5 data set was the flexibility allotted for both faculty and students, which can also be referred to as access, which is defined as free and unfettered access to technology. The ability of faculty to not be confined to a 2-3 hour lab period to finish all assignments was noted as a huge stress reliever. This not only allows students to work on their assignments at any time and any place but also gives faculty a longer period of time to respond to emails or address students' concerns. As noted by multiple faculty, no two students are the same. The quote highlights a faculty's take on the impact of online laboratories on flexibility.

"The second big advantage is that the student can take the lab at their own pace. And so, likely, you assign the lab and they can do it whenever they want. But not only whenever they want, but I've never met two students that are the exact same skill level."

Faculty are able to monitor students' progress and time put into the lab itself. Since each lab is to be done on their own time, the labs given out were usually individual. Due to a lack of workstations in the lab, in-person labs are generally collaborative and group-based. The ability to monitor students in a virtual setting allows for more individualized support, as well as confirmation that each student is doing their own lab.

2. Student Engagement with the Lab

Once again arising in our data sets, faculty recognize a lack of student engagement when conducting online labs in comparison to in-person labs. While the flexibility supplied by the online labs is important, faculty notes that students tend to lose their "sense of urgency" when completing the virtual option. This can be answered by a simple truth. The majority of students desire to be doing in-person labs. This is exhibited in this quote from a faculty member.

"I saw in all of my evaluations and feedback was from electrical engineering students saying that, "We need to work with hardware, I want to be in lab." So when I have students that want to be in lab, I'm going to do everything I can to make sure they're in lab."

Faculty are worried that students do not have to cognitively engage to complete the online version of the labs, resulting in a lack of understanding of the applications of concepts learned in lecture.

3. *Learning Outcome Differences*

In the case of remote labs, the software attempts to mirror the experience offered in in-person labs. The faculty noted in both data sets the difference between conceptual learning, which is provided in the online labs, and applicative learning, which is more prominent in the in-person labs. In the S1-S5 data set, faculty noted the importance of simulations and software implementation inside the workforce. This has led to the implementation of online labs that coincide with the in-person lab still being offered. The following is a quote from S4 that best proves this.

"'Okay, I'm getting hands-on practice to know how I'm building the circuits and what to expect in real life.' But then also allowing them the opportunity to still work on the simulated part of it, because the simulated circuits, while they are used in labs, you can use them for anything else."

B. Emerging Themes

1. *Strong Disconnect from In-Person to Remote Labs*

Although remote labs provide resources that replicate the physical labs, the experience lacks a certain nuance that can only be obtained in a tabletop setting. The faculty observed the lack of carryover from the online labs to the real labs, claiming that students were rigid in their processes when using physical components. The circuit's professors also noticed the students' willingness to blame the software before analyzing a problem in their own circuit. This excerpt from S3 explains this well.

"So in the [physical] lab, when you fail to hook the circuit up correctly, and the measurement gives you noise, the student knows they've got a test instrument in front of them. They know that they've got a circuit that they built, and the only conclusion they can come to is that they didn't build it correctly or they're not making the measurement correctly in some way… that's not the case with virtual labs."

All faculty interviewed appreciate the online labs and the capabilities they bring to the classroom, but they also realize that the lack of hands-on interaction will ultimately detriment the students.

2. *Incorporating Online Labs Around In-Person Labs*

Although faculty have implemented the in-person labs back into their semesterly coursework, the notion of online lab implementation is not lost among them. As noted by four of the five interviewees, they have taken to using the online labs as a pre-lab to acquaint the students with the concepts before they breadboard it in a limited amount of time. This allows the students to gain at least a minimum level of understanding before they move on to using real components in the physical lab. Here is a quote from S3 when asked about the benefits of assigning an online lab prior to the in-person lab.

"It's very comfortable for them. And yet when we start doing things that replicate what they will actually see at the bench, it reduces that barrier, that hurdle that they have to overcome to engage."

Aside from assigning the online laboratories as a pre-lab assignment, faculty also point out the supplemental uses. When there is a lack of resources to carry out hands-on labs, online labs have proven to be a suitable alternative for the faculty, as demonstrated by this quote.

"Now, having what we have here in UGA, my choice would be to have a combination, doing in-person experiments most of the time but using the online tools when the resources offered by the online tool are not available in the real world experiment."

3. *Preparation Time and Time Commitment*

A common observation made by faculty in the first data set is the big increase in preparation time to set up these labs. In the later data set, we see faculty in a state of revision as they constantly change their online labs to reflect the course content best. The mindset is well displayed in the following excerpt.

"The same thing when you're doing online labs, you need to dedicate time and look at technical materials to find references and see what kind of experiments can you put together, and spend some time thinking about the tool and in which ways you can profit from the tool."

As shown in multiple interviews, the circuits professors found that the time commitment towards online labs differed heavily from in-person labs. While the in-person time frame is a stressful time to answer questions and push students to finish the lab, the online lab offers a less stressful but more drawn-out approach to student care. Drawing back from the individualized support section, faculty can take their time and give students better answers through email than they can during in-person lab sessions. There appears to be a tradeoff that faculty can leverage depending on the assignment.

V. Conclusions

Circling back to our original research question - "Do faculty perspectives on the use of online laboratories shift over the course of the pandemic life cycle?", we were able to observe themes that were common between both data sets as well as new emerging themes that presented themselves solely in the new data set. The question then becomes, "What are the implications of this data?". From our data, we can see that faculty fully acknowledge that these online labs will not be a perfect replacement for in-person labs but can instead provide a different form of support to the students in different scenarios. The implementation of online labs as a pre-lab to acquaint students, or when the components required for the in-person lab are either expensive or scarce, or even just as a study tool for students' supplemental use. These are all possible applications for continuing to utilize online labs in a post-pandemic landscape.

As the technological scene continues to advance in academia, it is the job of researchers to understand the impacts that these technologies have on students and the classroom. With the rapid transition to online laboratories due to COVID-19, there is a shortage of knowledge on the impacts on both students and faculty. Future research stemming from this study could entail a deeper dive into the qualitative data derived from these two sets. Since we are drawing from two separate data sets from two different time periods, some sort of comparative analysis could yield interesting and thought-provoking results that could further a case for online lab implementation going forward.

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