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RHLab: Digital Inequalities and Equitable Access in Remote Laboratories

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RHLab: Digital Inequalities and Equitable Access in Remote Laboratories

Abstract

Recent research has highlighted the advantages of Remote Laboratories (RLs) in engineering education over traditional labs. RLs allow students to experience a full-fledged laboratory without compromising what could be accomplished when physically present in the lab. Taking advantage of content-rich remote laboratories promotes access to laboratory instructions for a diverse student body, including groups that may have limited access to in-person lab spaces for various reasons related to their location, time, or other constraints. While RLs offer advantages over traditional laboratories, there is still room for improvement in terms of ensuring equitable access and addressing digital inequality. In this paper, we conducted a mixed-method analysis using quantitative and qualitative thematic methods to assess the impact of RLs on equitable access to educational technologies. We administered a survey to students enrolled in a sophomore-level digital design course that utilized a remotely accessible Field Programmable Gate Arrays (FPGAs) lab, aiming to gauge their perspectives on equitable access and digital inequalities based on their experience with the remote lab. Our study confirms that RLs provide new opportunities for equitable access but also highlights the need to address digital inequality. Our analysis revealed a connection between low-income students and the challenges they face in studying under conditions of poor internet quality and limited access to internet-connected devices. This study aims to guide the development of a new remote Software-Defined Radio (SDR) lab for radio-frequency communications courses, that address issues related to digital inequality and provide equitable access to educational resources. Our findings offer insights for educators and policymakers seeking to promote inclusive and equitable education, especially in the context of remote learning.

Introduction

The COVID-19 pandemic has prompted a rapid transition to online learning and has led to the adoption of innovative teaching methods, such as RLs. However, it is important to address digital inequalities that could prevent some students from receiving a high-quality education. The loss of access to campus Wi-Fi and university devices has posed a challenge for some students, particularly those from lower-income families, who struggle with consistent internet connectivity and updating/maintaining their technological devices. This research is a continuation of a previous study [1] that analyzed the student perspective on remote hardware and equity in electrical and computer engineering education in the post-pandemic era. That previous study, which was based on a limited sample of students, revealed intriguing trends in students' perceptions of equity, which prompted us to conduct a more extensive survey, the focus of this paper.

According to Katz's definition [2], digital inequality refers to limited access to the internet and internet-connected devices. Initially, this issue was framed as a "digital divide", which divided the population into those who have access to technology and those who do not. However, recent research has shown that digital inequality is more complex than a simple binary classification [2]. For example, a 2021 survey conducted by the Pew Research Center [3] found that 99% of young adults reported having internet access. This indicates that the issue of digital inequality cannot be reduced to a simple "haves" versus "have-nots" dichotomy. Instead, it requires a more nuanced analysis, which should take into account alternative metrics that are available in the literature. Overall, it is essential to adopt a broader perspective when addressing digital inequality to ensure that everyone, regardless of their background or circumstances, has access to the resources they need to thrive in today's digital age.

In response to finding more accurate metrics on how students deal with digital inequality, some authors developed empirical methods to more realistically define who falls below the line of inequality. For instance, Katz used the concept of "under-connectedness" for those who don't have meaningful access to the internet and devices that enable connection to it [4]. Katz has identified that Americans who cannot afford internet service, have slow or unstable internet connections, share one computer among many people, or use a smartphone or tablet as their primary device for internet connectivity are more likely to belong to low-income groups.

Laboratories play a critical role in STEM education, particularly in the engineering field. This is because laboratory experiences are necessary to meet one of the seven student outcomes required for program accreditation by the Accreditation Board for Engineering and Technology (ABET): "an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions" [5]. Although RLs have been utilized in engineering education since the 1990s, they have gained increased popularity and attention since the COVID-19 pandemic [6].

Higher education institutions have taken various approaches to incorporating integrated RLs into their online engineering curricula, based on different criteria. Some universities have opted to develop their own RLs, while others have formed partnerships with other institutions to take advantage of reliable technical support. The Remote Hub Lab (RHLab) [7] has been involved in projects that use both of these approaches, collaborating with researchers in the United States and other countries [8]. Although the exact number of universities in the US utilizing RLs remains unclear, the increasing availability of remote education resources is evident. In 2018-19, the National Center for Education Statistics (NCES) reported that 79% of US universities offered online courses or programs [9], highlighting the growing trend of remote learning, which may also include the use of RLs. However, this percentage can vary based on the specific degree level or field of study. More recently, the National Student Clearinghouse Research Center reported a 3.2% increase in the number of undergraduates enrolled at primarily online institutions in fall 2022 compared to the previous year [10]. Given this trend, it is crucial to design RL systems with a lens of equity to ensure that all students have access to opportunities for success.

Methodology

This study presents an evaluation of students' perspectives on educational factors associated with digital inequality using both a survey and semi-structured interviews, with the survey results being reported in this paper. This work builds upon a previous study that surveyed a small sample of students in a sophomore-level digital design course on their general perspectives of equitable access and RLs[1].

Previous research has extensively studied survey and interview methods. Greene [11] developed a conceptual framework to guide the design and implementation of mixed-method evaluations, drawing upon various empirical evaluations. This framework proposes five types of mixed methods that highlight the importance of using them in evaluation research, as they offer a pathway to increase the rigor and credibility of findings, and provide a more comprehensive understanding of complex evaluation questions.

Creswell [12] emphasized the importance of mixed-method studies that incorporate both quantitative and qualitative data in 2004. Quantitative data provides a means for researchers to assess specific questions or hypotheses, while qualitative data enables them to observe participants and ask flexible and dynamic open-ended questions. Both types of data are essential components of mixed-method research, but their implementation and handling can differ significantly.

Our study can be considered a complementary mixed-methods design, as it seeks to elaborate, enhance, illustrate, and clarify the results from one method (interviews/focus groups) with the results from the other method (surveys), following Greene's evaluation type. Furthermore, the way we integrate data in Creswell's mixed-method design can be classified as an exploratory sequential design, as we first explore a problem where students may be understudied. There are several studies that recommend using mixed surveys and interviews to present results with rigor. However, it is important to note that there are other data collection methods, such as diary data, which can access certain aspects of student experiences that interview methods may not be able to efficiently capture, particularly in stressful situations [13].

This paper presents a survey and focus group study that covers three main areas of interest: Connectivity, Digital Equity, and Demographic data. The Connectivity section aimed to assess the accessibility and ease of use of the tools and technology used, while Digital Equity described technical aspects of internet connectivity and device usage. Demographic questions aimed to gather information on class characteristics. The interviews were performed in the form of focus groups to obtain uniform data collection of people's opinions, feelings, and perceptions [14]. We first identified focus group participants based on demographic data, such as low-income backgrounds, ethnic groups traditionally underrepresented, or first-generation college students, and invited them to participate. However, this paper mainly focuses on the quantitative data results, as the qualitative data is still a work in progress.

The survey included 10 sections and was delivered online using Google Forms to a class of 85 students from the electrical and computer engineering department, where 83 students completed the survey. This paper discusses four of those sections: Preliminary Information (Q1-2), RL Internet Connectivity (Q3-7), Digital Equality (Q8-14), and Demographic Data (Q15) and

Feedback (Q16). Table 1 lists all the questions by order, format, and topic. The other six sections are discussed in another paper that examines RLs with a stronger focus on Diversity, Equity, and Inclusion [15].

Table 1: Student experience survey breakdown

Section	Question Number	Question Format	Topic
Preliminary Information	Q1	Multiple Choice	Prior use of remote hardware before taking the course
	Q2	Short Answer Response	Explanation of answer to Q1
Remote Lab Internet Connectivity	Q3	Multiple Choice	Frequency of Internet access on a normal day
	Q4	Multiple Choice	Frequency of dropped Internet connections
	Q5	Numerical Free Response	Internet Speed Test; Download Speed (Mbps)
	Q6	Numerical Free Response	Internet Speed Test; Upload Speed (Mbps)
	Q7	Numerical Free Response	Internet Speed Test; Latency (ms)
Digital equality	Q8	Multiple Choice	Preference of Wi-fi signal (campus vs home)
	Q9	Multiple Choice	Technological maintenance to your internet connected devices
	Q10	Multiple Choice	RAM memory of your personal computer
	Q11	Multiple Choice	Type of Internet at home (Wired vs Wireless)
	Q12	Multiple Choice	Device to access Remote Lab
	Q13	Multiple Choice	If internet devices are shared with other members of the family
	Q14	Multiple Choice	Familiarity with Remote Laboratories
Demographic Data & Feedback	Q15	True/False	Do you identify coming from a low income background?
	Q16	Short Answer Response	Drawing from your remote lab experience this quarter, what factors are important to you when considering equitable access?

Quantitative results

The first two survey questions aimed to determine the students' prior experience with RLs. Q3 asked students how often their internet connection drops. Figure 1 shows the overall results, which are not immediately informative. However, when the data is analyzed separately for low-income students and non-low-income students (as captured by Q8), it becomes apparent that unstable internet connections are more prevalent among low-income students. Only a small proportion of this group has never had to deal with such issues, as shown in Figures 2 and 3.

These findings are consistent with Gonzales' research [16], which suggests that digital inequality should be viewed as a state of "dependable instability" rather than a time-limited experience.

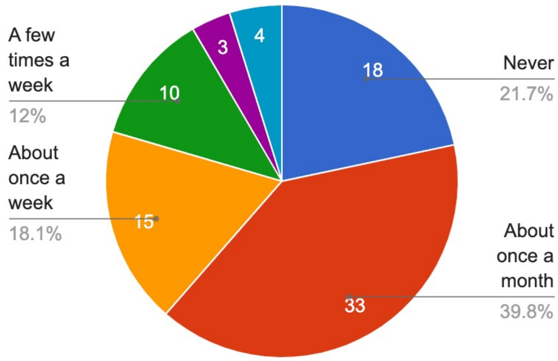

Figure 1: Frequency of dropped Internet connections experienced by the students

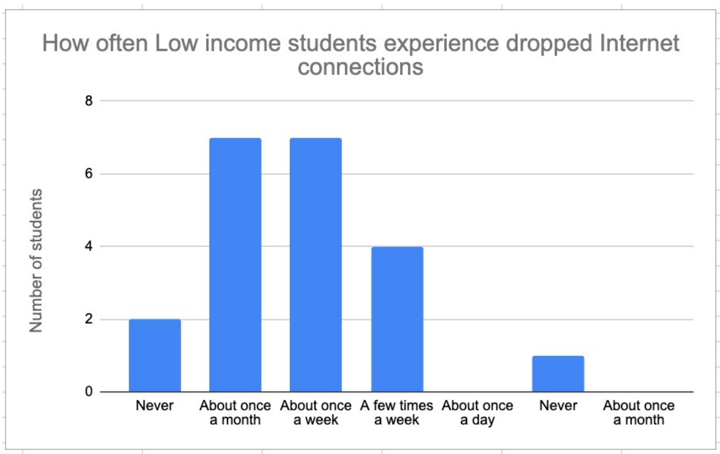

Figure 2: Frequency of dropped Internet connections experienced by the low-income students

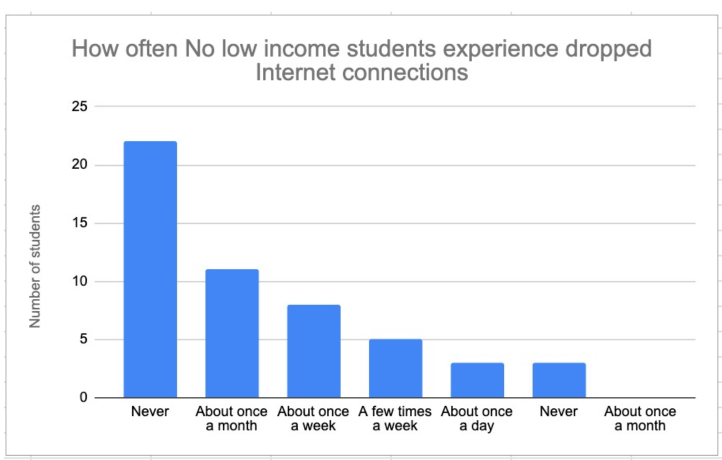

Figure 3: Frequency of dropped Internet connections experienced by the NO low-income students

Q8 asked students about their preferred Wi-Fi quality, whether it be at home or on campus. The results showed that 27.7% of students preferred the Wi-Fi on campus, which could indicate dissatisfaction with their home Wi-Fi quality. Figure 4 illustrates this. However, when only low-income students are considered, this preference jumps to 43.5%, suggesting a significant correlation between low-income students and digital inequality. Figure 5 presents these results.

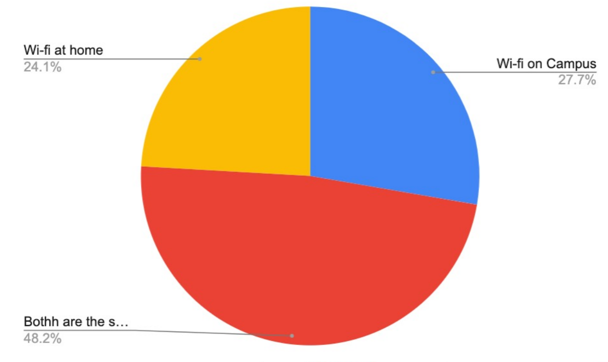

Figure 4: Total students that compare the quality of Wi-fi connection their university duties

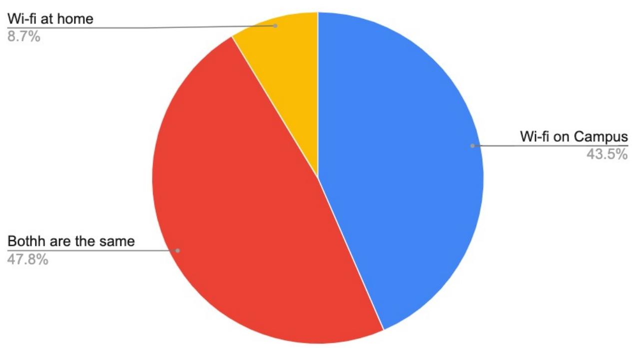

Figure 5: Students from low-income that compare the quality of Wi-fi connection their university duties

Figure 6 demonstrates that the majority of students tend to perform technological maintenance on their internet-connected devices, such as laptops, tablets, or cellphones (63.9%). However, when we analyzed the data only for low-income students, the proportions changed. As shown in Figure 7 (left), more than half of the students (52.9%) from low-income families reported not performing technological maintenance. This finding is consistent with Gonzales' et. al. research [17], which found that lower-income students often experience delays in resolving technological issues, which can be time-consuming and negatively impact their ability to keep up with their coursework. Figure 7 (right) also illustrates that among non-low-income students, the proportions are the opposite, which further supports the idea that digital inequality is associated with low-income students.

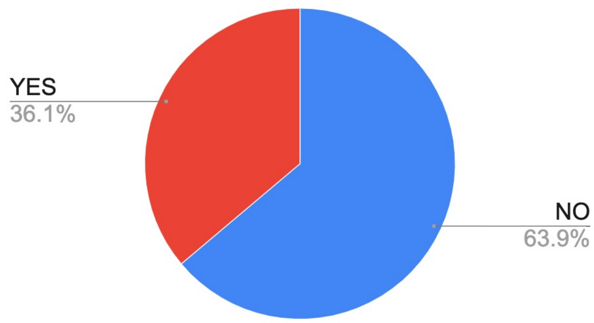

Figure 6: Students that apply technological maintenance to their internet connected devices

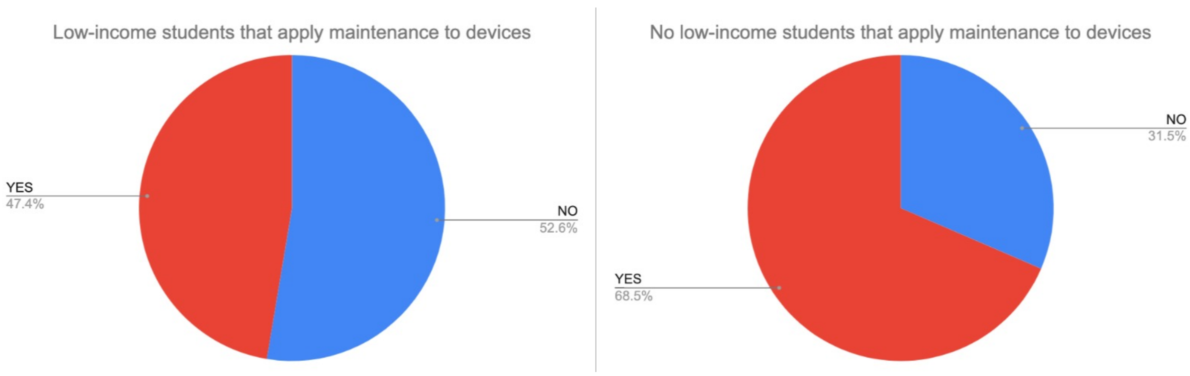

Figure 7: Low-income (left) and No low-income (right) students that apply technological maintenance to their internet-connected devices like Laptop, tablet, cellphone

We also investigated whether other questions related to technology, the internet, or devices connected to the internet could provide evidence that digital inequality is linked to low-income families. However, we did not find any noteworthy findings in relation to the size of RAM memory of students' laptops, the type of internet connection used, or whether students had to share computer devices with other family members. Figures 8 and 9 and 10 show the results of these questions.

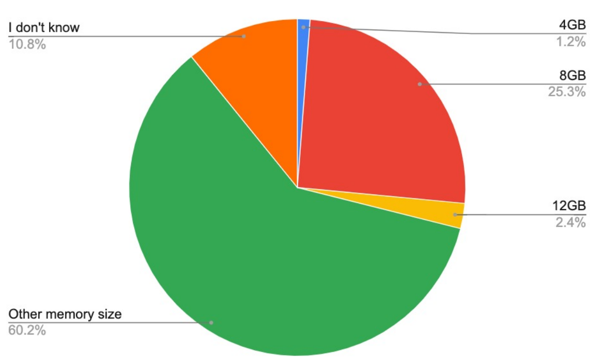

Figure 8: Size of RAM memory of total students' laptop

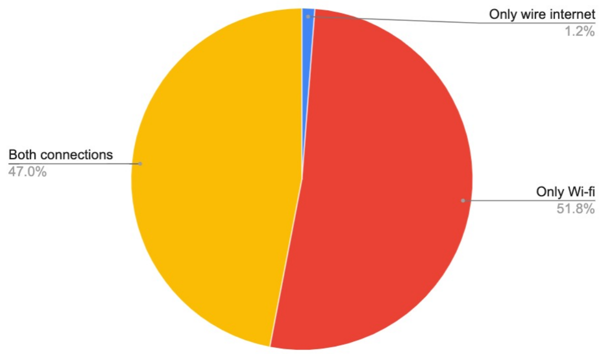

Figure 9: Type of internet connections that total students use

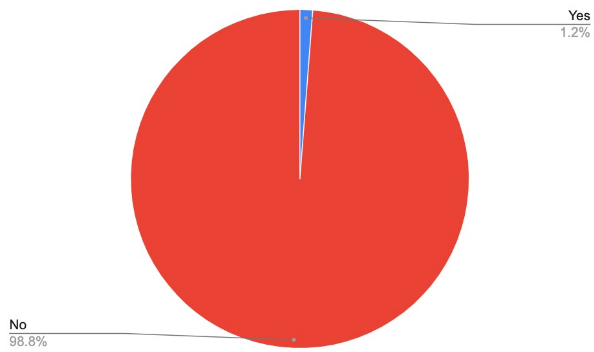

Figure 10: Amount of total students that have to share computer with other members of their family

Qualitative results

In the following section, we will present a qualitative analysis of the responses to the question "Drawing from your Remote Laboratory's experience this quarter, what factors are important to you when considering equitable access?" (Q16). Similar to Atienza & Hussein's study [1], we used six "Factors of Equitable Access" to code the responses: "Accessibility", "Quality of Internet", "Affordability", "Ease of Use", "Convenience", and "Other factors". These codes are listed in Table 2, and the results of the coding process are depicted in Figure 11. Out of 83 responses, the majority of them were related to "Accessibility" and "Quality of Internet", which will be analyzed thematically.

Analyzing "Accessibility" as a factor of equity access:

Theme 1: 24/7 availability

> *"Equitable access is being able to access the remote lab from anywhere and at any time of day."*

This excerpt provides insights into the significance of having a facility that guarantees equitable access. The responses emphasize the importance of not only having a RL that can be accessed

Table 2: Factors of Equitable Access

Code	**Associated Phrases, Mentions, and Ideas**
Accessibility	24/7 availability, Offering equal opportunities for everyone, Reliability
Quality of Internet	Internet is all you need, Off-line options, Importance of Internet quality in academic success
Affordability	Free, Cost, Lab fee
Ease of Use	Functional, Usability, Quality of web interface, Not browser or OS-specific, Ease of Access
Convenience	Convenient, Schedule Flexibility (Anytime), Location Flexibility (Anywhere), Didn't require transport, No need to worry about damage
Other factors	Free to user's choice

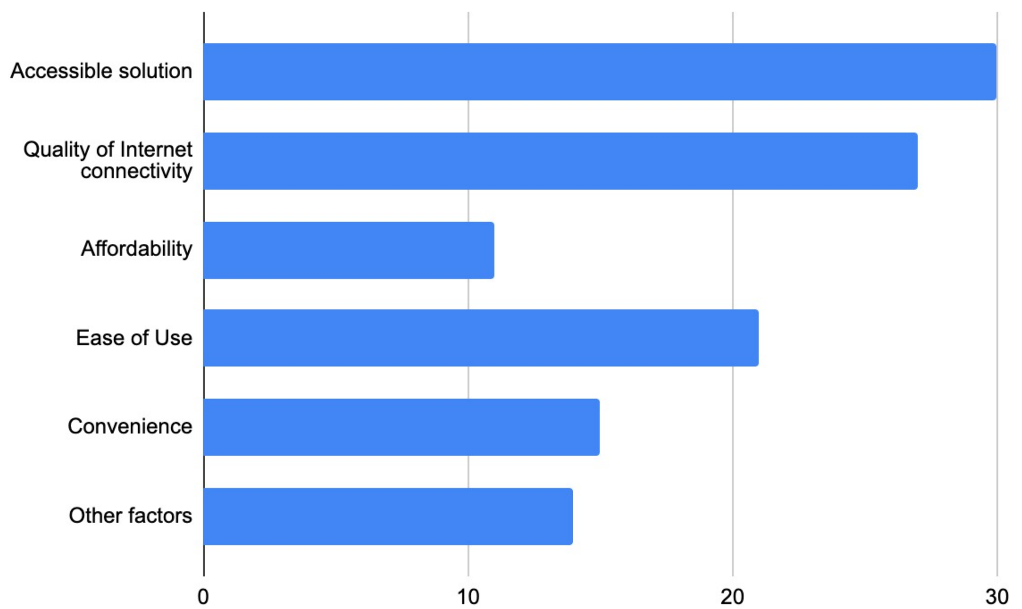

Figure 11: Student-mentioned Factors of Equitable Access vs. number of mentions in free response

24/7 from any location but also taking actions to ensure a level playing field for all students regardless of their socioeconomic, racial, and ethnic background. Students expressed appreciation for the fact that with RLs, access is not prioritized for anyone, and everyone has the same amount of time and resources, resulting in an equitable experience for all.

Theme 2: Offering equal opportunities for everyone

> *"The lab ensures that every student has an opportunity to access the devices."*

The students' responses demonstrate how RLs help them succeed in their coursework in various scenarios. For example, part-time job students are able to work on labs from the comfort of their own homes instead of having to commute to school. RLs are also seen as a more equitable option for students who cannot afford lab fees. Additionally, RLs are beneficial for students with physical disabilities as they eliminate the need to physically attend the lab, as well as the challenges associated with tasks such as wiring, button-pressing, or switch-flipping.

Theme 3: Reliability

> *"If something is not really reliable that to me is not equitable access because every day you have to worry about if it will work or not."*

The student's experience of testing a new RL system underscores the importance of offering a reliable user experience. While RLs can simplify equipment connection and configuration, they also introduce new challenges such as account creation and registration procedures that can pose additional difficulties. Therefore, the laboratory's design should prioritize creating a perception of reliability to enhance user confidence. Overall, the quotes presented emphasize the significance of providing equitable access to RL facilities for students of diverse socioeconomic, racial, and ethnic backgrounds. RLs offer a level playing field, enabling all students to access the same resources and have an equal chance to succeed. RLs are especially beneficial for part-time job students, financially challenged students, and those with physical disabilities. The laboratory's design should prioritize creating a reliable user experience and overcoming any challenges to enhance user confidence.

Overall, the quotes presented emphasize the significance of providing equitable access to RL facilities for students of diverse socioeconomic, racial, and ethnic backgrounds. RLs offer a level playing field, enabling all students to access the same resources and have an equal chance to succeed. RLs are especially beneficial for part-time job students, financially challenged students, and those with physical disabilities. The laboratory's design should prioritize creating a reliable user experience and overcoming any challenges to enhance user confidence.

Analyzing "Internet quality" as a factor of equity access:

Theme 1: Internet is all you need

> *"Since you only need to be connected to the internet to access it, it's fairly equitable to access."*

The students' responses center around the crucial role of internet access in accessing RLs and other online resources. Many express gratitude for the opportunity to work with hardware on their own schedule, as this flexibility allows them to complete coursework at their own pace. For example, one student noted how RLs were particularly helpful during a busy week, as they could only work on lab assignments during the weekends. Ultimately, the students highlight the essential nature of reliable internet access in achieving an equitable and successful RL experience.

Theme 2: Off-line & alternative options

> *"Get free internet access or rent a computer from my university if I need it."*

In the current reflection, students highlighted the financial challenges associated with internet access and having devices connected to the internet. One student suggested that providing free internet access or offering the ability to borrow or rent a university computer could ensure equal access for all. Another student mentioned that paying for internet services can be prohibitively expensive, especially for those who do not live close to campus due to financial constraints. Therefore, remote lab developers should prioritize creating tools that are less dependent on resources that may be inaccessible to some students. This would help alleviate the digital inequality barrier and promote more equitable access to remote lab resources.

Theme 3: Importance of Internet quality in academic success

> *"Students who are not fortunate to have consistent internet access may be unfairly disadvantaged in an online academic setting."*

They highlight the importance of internet speed and how it affects the lab's accessibility. Also, they suggest RLs may require additional support and accommodations to ensure equitable access. Therefore, it is crucial to consider the lab's compatibility with different internet types, speeds, and computers and to provide proper feedback and support from the teaching staff.

The responses from students highlight the critical role that internet speed plays in accessing RLs and stress the need for additional support and accommodations to ensure equitable access. Therefore, it is essential to consider the compatibility of the lab with different types of internet and computers and to provide adequate feedback and support from the teaching staff. These results underscore the importance of internet access in providing equitable access to RLs, with the need to consider internet speed and compatibility with different types of computers. Additionally, to ensure equity in RLs for low-income students, possible solutions include providing free resources such as internet access or developing lightweight or offline versions of RLs.

Discussion

In 2022, the research team of the Remote Hub Lab (RHLab) developed a Software Defined Radio (SDR) Remote Laboratory (RELIA) to be used in teaching signal processing and system communications [18]. SDR technology has the advantage of building multiple wireless communication prototypes by only modifying a few lines of software which is optimal for engaging students who can probe communications theory in the real transmitter and receiver hardware[19]. The RELIA project is open source and educators will be able to replicate the software, and the setup and use it in their institution with the open-source WebLab-Deusto9 software.

From "Analyzing Internet quality Theme 2 - Off-line and alternative options," students discuss the challenges of setting up a RL using devices other than laptops, particularly in areas with unstable internet connections. These issues are a guide to developing an additional version of the laboratory called RELIA Lite, which can be accessed from mobile devices such as tablets and cellphones.

To perform a radio experiment using RELIA, the user typically needs to adjust many parameters, some of which must be modified dynamically to monitor the data stream and evaluate its quality. While this can be done easily using a computer, it can be tedious and challenging to do so on a cellphone due to the small screen size. To address this issue, RELIA Lite will include a list of pre-configured experiments in which most of the common parameters are already set, letting the user modify the most important parameters making it easier to configure an experiment. Figure 12 shows a regular plot of data streaming view from a laptop while Figure 13 shows how it would be seen from an iPhone SE. RELIA Lite is currently under development and will be discussed in future publications.

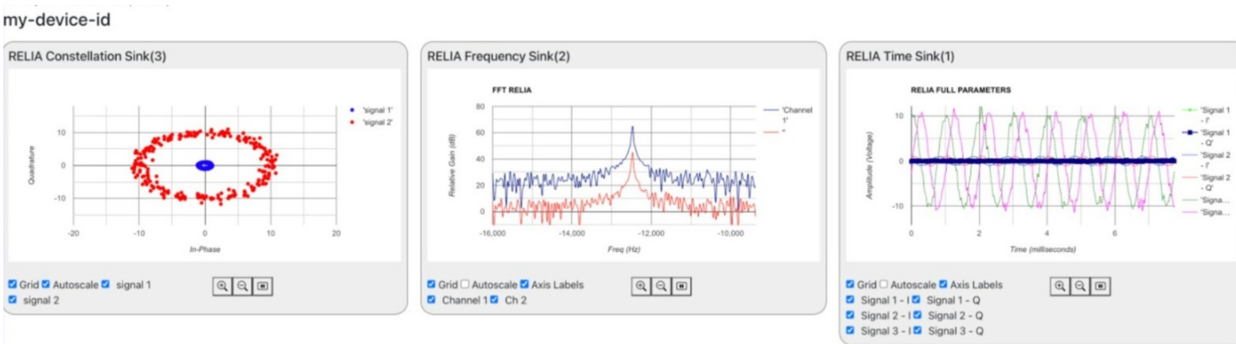

Figure 12: RELIA configuration in a laptop's view

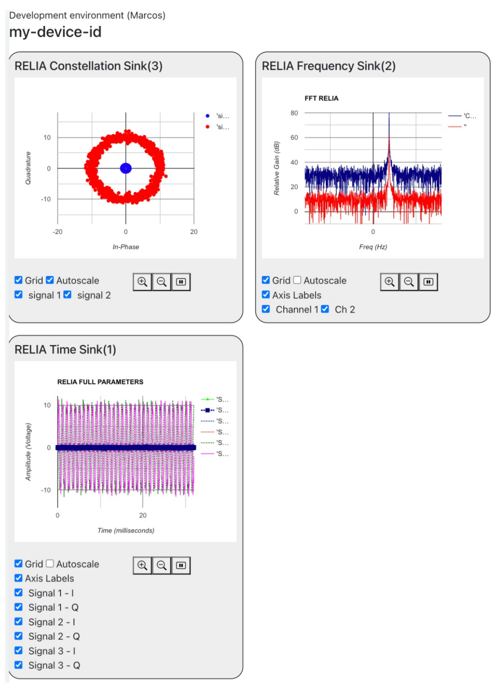

Figure 13: RELIA configuration in a smartphone's view

Conclusions and Future Work

The objective of this study is to evaluate the impact of remotely accessible FPGA labs (RLs) on equitable access and digital inequality among undergraduate students taking a digital design course. While RLs have the potential to promote equity, the modernization of the internet can worsen digital inequality, which contradicts the primary goal of RLs in education. Digital inequality poses a significant challenge to some students, hindering their college success. Although various proposals on how to measure digital inequality exist, no comprehensive metric has been established. Our study revealed that students from low-income households experience difficulties with internet quality and connecting devices to the internet. Economic factors play a critical role, but a lack of technological preparedness at an early age also contributes to the issue.

Quantitative data indicate that poor Wi-Fi quality at home and a lack of maintenance on internet-connected devices are two factors that hinder college success among students from low-income households. However, factors such as outdated computers, sharing computing devices with family members, or the type of internet connection do not appear to have a significant impact on students' educational progress. Qualitative data confirmed that RLs are a useful tool for learning and promoting equitable access, but the internet can trigger digital inequality that may impede equity among certain demographics.

In response to the issue of equitable access, the RELIA Lab was created, in line with the core goals of Engineering Instructional Laboratories. A Lite version of the lab is also under development to address digital inequalities and ensure access for students using mobile devices like cell phones or tablets. To gain a deeper understanding of digital inequality among students, we plan to conduct additional interviews and focus groups. Exploring the situation of other minority groups will provide valuable insights and reveal new information. Lastly, conducting more interviews with students and instructors will aid in constructing a Lite version that meets high educational standards and student requirements.

Acknowledgement

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