The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #42982

Thematic Insights from Focus Groups: Addressing Digital Inequalities in Remote Laboratories for Equitable Engineering Education

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Abstract

The integration of Remote Laboratories (RLs) into engineering education has influenced instructional methodologies. Their cost-effectiveness, low maintenance, and ease of accessibility have made them an appealing option for some educational institutions to explore inclusion in their curricula. This pedagogical shift has sparked discussions about potential digital inequalities that could emerge from the advanced technological demands of RLs. In this context, we explore the impact of digital inequalities on equitable access within Remote Laboratories (RLs). This paper builds on the findings of our previous study that involved students using a remote lab equipped with Field Programmable Gate Arrays (FPGAs). While our prior survey-based research highlighted RLs' potential to enhance educational equity, it also suggested that the evolution of internet technology might lead to digital inequalities. These inequalities particularly affect students from low-income backgrounds who may encounter issues with internet quality and device connectivity, often exacerbated by inadequate technology maintenance, hardware problems, and logistical issues related to public access. This paper aims to further investigate these challenges through detailed focus-group discussions. These discussions are designed to explore the complexities of the challenges students face, assess the impact of remote labs across three levels of inequalities, and propose potential solutions and interventions. Data from the focus groups will elucidate the 'how' and 'why' behind the survey data collected from students, offering a deeper, human-centered view of their experiences with digital inequalities. Insights from this research will provide critical input for developing and assessing remote labs tailored specifically for radio-frequency communications courses.

Introduction

Remote laboratories have gained significant traction in engineering education due to their ability to enable experimentation from any location with an internet connection, thus eliminating geographical constraints and offering scheduling flexibility [1–5]. They also alleviate financial burdens associated with setting up and maintaining physical lab infrastructure. Furthermore, remote labs contribute to equitable access, expanding opportunities for students from lower-income and underrepresented minority backgrounds, especially through community colleges [6, 7].

However, while remote labs offer these benefits, they also present challenges, as they necessitate access to stable internet connections, modern devices, and proficiency in using online platforms, potentially widening the technological barrier for certain groups and triggering digital inequalities that can significantly hinder the achievement of high-quality education for all students equally [8]. Quantifying digital inequalities within the context of remote labs presents a challenging task due to the multifaceted nature of these disparities [9]. Unlike traditional metrics of access, such as internet connectivity or device ownership, digital inequalities in remote labs encompass various dimensions, including technological proficiency, access to specialized software, and familiarity with online learning platforms. Moreover, measuring these disparities requires nuanced assessments that account for socio-economic factors, educational backgrounds, and cultural contexts [10]. Additionally, digital inequalities manifest differently across diverse populations and settings, making it difficult to develop standardized metrics that accurately capture the extent of disparities [11]. As such, evaluating and addressing digital inequalities in remote labs necessitate comprehensive approaches that consider the complex interplay of socio-technical factors influencing digital participation.

The Remote Hub Lab (RHL/RHLab) [12] research group's efforts in democratizing educational access have studied the impacts of digital inequalities to contribute to remote labs development by presenting a study that analyzed the student perspective under a focus group setting. The findings from this study provide valuable insights that will inform future remote lab initiatives aimed at bridging the digital divide.

Background

Over time, extensive research has been conducted on digital inequality in education, addressing the challenges faced by students in accessing equitable resources. The study of its determinants and social effects has been motivated by the lack of equal access [13]. This digital disparity is significantly influenced by the country or region of residence, with notable variations in levels of technology access, internet connectivity, government policies, technological infrastructure, and investment in digital education among different countries [14].

Researchers have categorized digital inequalities into three levels [15, 16]. The first level refers to unequal internet access, where those who have access to the network are segmented mainly by population characteristics [17]. This group includes individuals who cannot afford the service, have slow or unstable connections, share devices, or primarily use smartphones or tablets for connectivity [18]. The second level is more intricate to delineate, but essentially measures individuals' mastery and utilization of Internet technology. Within this category, active content creators are considered, as opposed to passive content consumers [19]. As for the third level, it could be considered an extension of the first and second [20]. It refers to those capable of generating wealth through the use of the internet, (i.e., converting their access into monetary gains) [21]. In the educational field, it is challenging to find direct evidence of the digital gap at this level, as measuring students' incomes is not straightforward. However, it is important to mention that research has shown how digital access and skills can expand job opportunities as a result of successful participation in online resources [22].

Understanding how digital inequalities impact remote learning requires methods like surveys or focus groups [9]. Similarly, in remote laboratories, researchers could explore how students' experiences are connected with the three levels of digital inequalities. Focus groups provide information that, through Thematic Analysis (TA), permits the extraction of insights from qualitative data [23]. TA involves systematic steps such as data familiarization, theme identification, and report production [24, 25].

In our previous research [26], three central themes—accessibility, internet quality, and affordability—were identified as most relevant. In this paper, these themes were also found to be the most frequently occurring during the coding process, further highlighting their importance in understanding digital inequalities in remote laboratories.

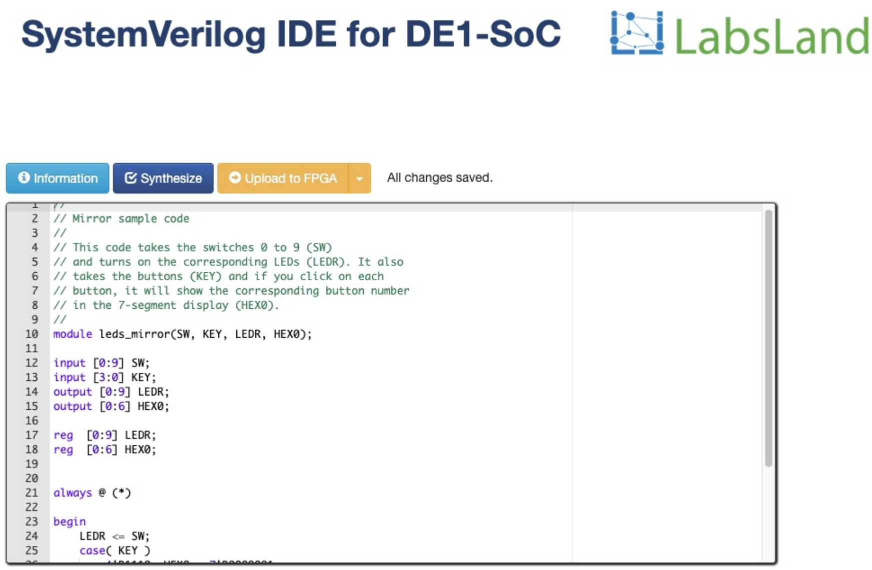
Methodology

This study involved five focus group sessions with a total of ten sophomore students enrolled in the electrical engineering program at a public university in the Western United States. These students had previously completed a digital design course that included both theoretical sessions and six laboratory assignments. During these assignments, students engaged in hands-on experimentation using remotely accessible DE1-SoC Terasic FPGA boards through the Remote Hub Lab (RHLab) [12] . Figure 1 illustrates the setup of the remote lab, which features 36 FPGA boards accessible remotely via a web browser. This lab is integrated into the LabsLand global network of remote laboratories [27]. The students had also participated in a prior survey [26]. The study was approved as an exempt study under IRB ID MOD00017662.

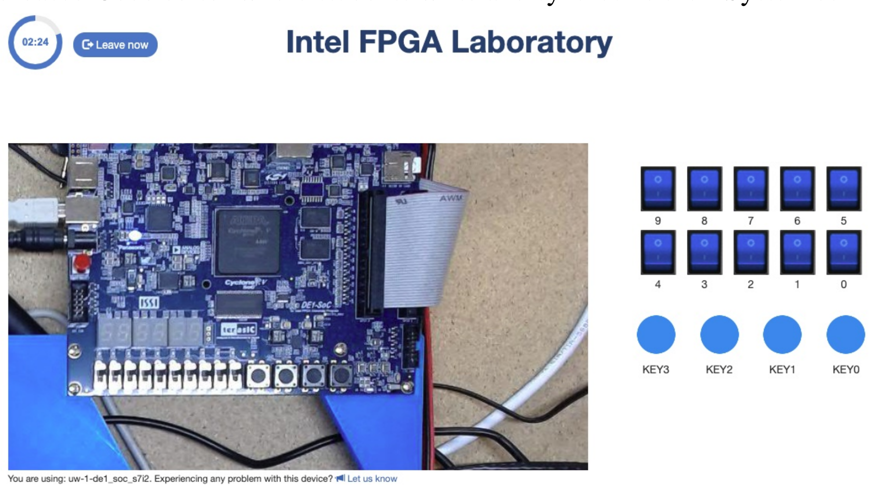
(a) Structures that house DE1-SoC boards.

Focus Groups Details

Five focus group sessions were organized online via Zoom to explore topics related to equitable access. Each session followed a structured format, with the same set of questions posed to



(b) Web-based Code editor where students write and synthesize their SystemVerilog code



(c) Student's view of the remote FPGA boards via a webcam.

Figure 1: RHLab remote FPGA lab

participants. The discussions were divided into three sections within one day, with two additional sessions scheduled for the following week at different times to accommodate students' availability. All focus group sessions were recorded using audio-files, and subsequently, the recordings were transcribed. A meticulous transcription process was employed to produce clean transcripts, which involved removing repetitions, false starts, and any potential errors to enhance readability for the reader. Once transcribed, the recordings were securely deleted.

At the beginning of each session, participants were required to provide informed consent, granting permission for the sessions to be recorded and for their data to be used, ensuring anonymity and confidentiality. These sessions facilitated round-table discussions involving ten students selected to represent minority groups, including individuals from low-income backgrounds and various racial or ethnic minorities, as detailed in Table 1.

Table 1: Participants in the focus groups

	Gender / Gender Identity	Racial or Ethnic Groups	Enrollment Status	Low Income Background	First Generation College Student	LGBTQ+ Community?	Person with a Disability
P1	Cisgender Man	Hispanic/Latinx	Full time	No	No	No	No
P2	Cisgender Man	Native American /Alaskan Native	Full time	Yes	No	No	No
P3	Cisgender Man	White	Part time	No	Yes	No	No
P4	Non-Binary /Gender Non-Conforming	Asian American/ Asian	Full time	No	No	Yes	No
P5	Cisgender Woman	Asian American/ Asian	Full time	Yes	No	No	No
P6	Cisgender Man	Asian American/ Asian	Full time	No	No	No	No
P7	Cisgender Woman	Middle Eastern/ North African	Full time	No	No	No	Yes
P8	Non-Binary /Gender Non-Conforming	White	Full time	No	No	No	No
P9	Non-Binary /Gender Non-Conforming	Asian American/ Asian	Full time	No	No	Yes	No
P10	Cisgender Man	Asian American/ Asian	Full time	No	No	No	No

The focus group sessions were conducted in English, with a duration of 60 minutes each. Each session was structured to accommodate approximately 20 minutes of discussion for each topic, facilitating participant interaction and the sharing of perspectives. The discussions were centered around eight predetermined questions, providing students with ample opportunity to respond and engage in free discourse on related topics. The questions posed to the participants are detailed in Table 2, guiding the flow of conversation and exploration of relevant themes.

Table 2: Focus Group Student's Questions

Section	**Question Number**	**Topic**
Equitable Access	Q1	Do you think that diversity equity and inclusion can be achieved through technology technology such as the remote labs?
	Q2	What are the advantages and disadvantages of each option in providing equitable access to engineering education?
	Q3	Which option do you believe is more affordable and convenient for students from disadvantaged communities?
Digital Inequalities	Q4	Did you encounter any issues with internet connectivity during your lab usage that affected your participation or made you feel excluded?
	Q5	Do you think using the remote lab requires a significant background in internet skills?
	Q6	How has the use of Remote Labs enhanced your internet/online skills?
	Q7	How do remote labs compared to in-person labs impact your interactions with diverse individuals (instructors, TAs, and classmates)? Do they strengthen, weaken, or have a neutral impact?
	Q8	How has the use of Remote Laboratories supported your engagement in digital environments and content creation?

The selection of questions was related to the subject under study. Questions Q1-Q3 aimed to uncover specific digital inequalities experienced by students in their day-to-day lives. Questions Q4-Q8 delved deeper into students' perceptions regarding accessibility, internet quality, connectivity, and affordability.

Qualitative content analysis encompassed the literal transcription of speeches and the establishment of categories derived from the main questions to construct the analytical framework. Additionally, the elements emphasized by focus group participants were taken into account. This initial data engagement facilitated the identification of emerging preliminary themes, leading to a more comprehensive and in-depth analytical examination.

Results

The focus group data has provided rich insights into students' perspectives. Below is the list of their most relevant ideas:

Analyzing "Accessibility" as a factor of equity access:

Theme 1: Technology as an Equalizer:

Access to new technology levels the playing field, allowing students to overcome barriers and gain a competitive edge in learning about various topics. This perspective was emphasized by several students, as evidenced by the following statements:

> **P5:** *"I believe technology plays a crucial role in acquiring new knowledge. Being exposed to computers and accessing new technology from a young age has given me an advantage, particularly in learning about new topics."*

> **P7:** *"I believe the remote lab offers the most accessible option for using FPGAs because it can be accessed from home or any system. In contrast, purchasing an FPGA is expensive, creating a financial barrier. Additionally, borrowing FPGAs from the lab may not be feasible due to limited availability, especially considering the large number of users."*

Theme 2: Financial Considerations and Commuting Costs:

In this theme, students underscore the importance of remote labs in alleviating additional expenses, such as transportation costs, thereby providing a more financially viable option for students, especially those with added responsibilities like childcare. For instance, one student remarked:

> **P3:** *"Commuting to school during peak hours can cost around $15-$16 a day in gas alone. While I don't consider myself from an underprivileged background, needing to work is just a reality based on my age. However, if you're someone like a younger student with additional responsibilities like childcare, reducing trips to campus can be a financial relief since transportation costs can add up."*

Another student, hailing from a country with limited financial resources in rural areas, highlights the financial constraints that can impede access to materials, making remote labs a preferable option.

> **P5:** *"I prefer the remote lab, especially considering my background in Thailand, where limited monetary resources often mean a lack of access to materials, particularly in rural areas where I grew up."*

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

Theme 1: Importance of Internet quality in academic success

Student acknowledge the potential financial hurdles associated with obtaining technology for remote labs, such as the expense of a quality laptop and internet access. Nevertheless, they note that university programs may assist in mitigating these costs.

P8: *"I understand that having good internet access and a quality laptop can be expensive. However, there are programs, such as those that lend out hotspots like libraries, which help make these resources more accessible. This assistance contributes to making the remote lab more accessible overall."*

Lastly, another student recognizes the cost of home internet access as a potential barrier but doubts that many students would solely invest in internet access for academic purposes.

P9: *"The only external factor I can think of is the cost of home internet access. However, I don't believe many students would solely pay for internet access just to use the remote lab. The Internet is generally used for various purposes beyond academics."*

Analyzing "Importance of Remote Labs in Creation of Content" as a second level of digital inequalities:

Theme 1: Facilitation of Creation Process

Respondents highlight how remote labs facilitate the creation process by providing a controlled environment where errors are more likely to be on the user's side, allowing for easier troubleshooting and experimentation with code and hardware.

P8: *"Remote lab was nice in the creation because since it was so controlled, you knew that if any errors were happening it was usually on your side or most likely was on your side."*

Also, respondents express a desire for opportunities to explore alternative problem-solving approaches and incorporate peer solutions into the learning process. They see remote labs as platforms that could provide valuable insights into optimizing engineering solutions.

P5: *"I'm often curious to learn if there's a more efficient way to solve a problem than the workaround I've implemented. It would be beneficial if there were opportunities to explore alternative problem-solving approaches. Incorporating peer solutions into the learning process could provide valuable insights into optimizing engineering solutions."*

Remote labs in driving creativity and collaboration among engineers. They emphasize how remote labs serve as collaborative tools that allow for teamwork and exploration of different skill sets, fostering creativity in engineering projects.

P6: *"Yes, absolutely. Like as an engineer to like help drives your creativity or like to improve on your quality you collapse with other people you work in a theme setting or like you work with other people to know what you're missing or what you need or what you already have your skill set. And I feel like remote lab is like a perfect collaborative tool for that aspect of engineering because again like physical lab can only like provide access to so many people."*

Discussion

This research was conducted to better understand the current challenges posed by digital inequalities and to use these insights to enhance the development of remote laboratories. By addressing these challenges, we aim to utilize technology to bridge the gap between learners with varying levels of digital access and resources.

Regarding the findings on focus groups, it's evident that the significance of remote labs extends beyond merely mitigating expenses related to essentials like laptops and internet access. While these financial considerations are significant, there exists another crucial aspect that remote labs address: accessibility for part-time students who may find it challenging to regularly commute to campus. For certain groups of students, such as part-time students, the ability to easily access campus resources can be limited due to various commitments, including work, family responsibilities, or other obligations. This highlights the dual benefits of remote labs: they not only alleviate financial strains but also provide flexible engagement opportunities, particularly beneficial for part-time students.

Moreover, our observations suggest that the significance of remote labs goes beyond just providing internet access and computing devices. The effectiveness of these educational tools must also take into account the socio-economic realities of the areas in which they are implemented. It's crucial to test remote labs under varied conditions to fully understand the digital inequalities that affect different user groups.

Despite the need for a high level of technological knowledge, the focus group feedback indicates that remote laboratories are an effective means to mitigate digital inequalities at the secondary level. Specific examples demonstrate how remote labs foster creativity and collaboration among colleagues. For instance, students have emphasized how the remote lab enabled them to collaborate on coding projects, troubleshoot issues in real-time, and exchange ideas through online forums and platforms. Moreover, remote labs encourage innovation by providing a controlled environment for individuals to explore alternative problem-solving approaches and experiment with different engineering concepts.

Moreover, the analysis of accessibility as a factor in equitable access emphasizes technology's role as an equalizer in educational opportunities. Many students stress the benefits of early exposure to computers and new technology. Additionally, they note the financial burden of commuting to campus, particularly for those with additional responsibilities such as childcare. Remote labs offer a financial reprieve by minimizing the need for frequent campus visits and reducing associated transportation costs, thereby enhancing accessibility for all students.

Through these findings, we aim to incorporate features into future remote labs guidelines to ensure equitable access. The MELODY model [28], for instance, is a comprehensive framework for implementing remote laboratories based on Software Defined Radio (SDR) technology in wireless communication courses. By incorporating insights from studies on digital inequalities, MELODY provides technical solutions that help close these gaps and promote equal access for all students. Currently, under this model, the RHL-RELIA [29] remote lab has been developed, marking a significant advancement in inclusive access to hands-on learning experiences. Further applications under the MELODY [30–33] are in development, demonstrating its potential to expand educational opportunities and bridge the digital divide in remote learning environments.

Conclusions and Future Work

This study has highlighted the crucial role remote laboratories play in addressing digital inequalities within engineering education. By facilitating access to essential learning resources, remote labs prove to be more than just cost-saving tools; they are vital for enabling inclusive education, especially for part-time students and those facing socio-economic challenges. The focus group discussions emphasized that while remote labs mitigate some financial burdens, their true value lies in providing flexible and accessible educational opportunities. This has been particularly significant for students who otherwise face barriers to accessing traditional campus resources due to logistical constraints. Furthermore, our findings underline the importance of considering socio-economic contexts when implementing technological educational tools, to ensure they are effective across diverse environments.

Looking ahead, our research will continue to develop and expand the capabilities of remote laboratories to further enhance their accessibility and effectiveness. We plan to improve the technological infrastructure of remote labs, ensuring they are robust enough to handle advanced simulations and support a dynamic learning environment. This includes integrating insights from the current study into enhancing the MELODY model's framework, specifically focusing on strengthening components related to equitable access. Additionally, the RHL-RELIA lab is being adapted for use across the USA and Latin America and will be available in Spanish, English, and Portuguese. This multilingual and multicultural expansion is aimed at accommodating the diverse educational needs and cultural nuances of students in different regions. By assessing and tailoring remote lab technologies to meet specific regional and cultural requirements, we aim to deepen our understanding of how digital inequalities impact educational outcomes globally and leverage these insights to mitigate such disparities. This comprehensive approach will ensure that remote labs continue to serve as powerful tools for promoting equitable education, contributing significantly to the global endeavor of making quality engineering education accessible to all.

Acknowledgement

RHL-RELIA project is funded by the National Science Foundation's division of undergraduate education under award number 2141798.

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