Student Perspectives on Remote Hardware Labs and Equitable Access in a Post-Pandemic Era

Florence Atienza
Electrical and Computer Engineering
University of Washington
Seattle, WA, USA
fmna@uw.edu

Rania Hussein
Electrical and Computer Engineering
University of Washington
Seattle, WA, USA
rhussein@uw.edu

***Abstract*—This Research Full Paper builds on a prior study that compared overall student performance between in-hand versus remotely accessible hardware in digital design courses. The COVID-19 pandemic necessitated a global educational shift to emergency online learning that led to rethinking the delivery of engineering labs. The prior study showed that, amidst pandemic-necessitated online learning, student understanding was not impeded by the incorporation of remotely accessible hardware into the course curriculum; rather, using remote hardware resulted in similar or better learning outcomes. In this paper, we analyze the remotely accessible hardware lab through the lens of equity, investigating the student perspective on equitable access and the remote lab experience. The study accomplishes this goal by surveying students of a junior-level digital design course who use a remotely accessible hardware lab for completing their assignments. The survey aims to determine the factors deemed important by today's learners – those who have experienced remote learning for approximately two years of their educational careers – when considering equitable access and remote labs. Survey questions utilized the multiple-choice, semantic differential scale, and Likert scale formats for quantitative analysis as well as inductive coding of freeform responses for qualitative analysis. Initial findings from the survey are the key considerations of the surveyed students which include Factors of the Remote Experience (FREs) and Factors of Equitable Access (FEAs). FREs and FEAs specifically relate to the Student's *Access to Electronic Devices*, the Student's *Environment Outside of Class*, the Student's *Schedule*, the Student's *Internet Quality*, the lab's *Learnability*, the lab's *Web Interface Design*, the lab's *Convenience*, the lab's *Overall Positive Experience*, the lab's *Ease of Use*, the lab's *Internet Quality*, and the lab's *Affordability*. Rooted in the online learner's experience, these results contribute to an improved understanding of how students perceive equitable access to engineering education which shall guide better-informed advancements in the field in a post-pandemic world.**

Keywords— Remote Laboratory, Equity, Distance Learning, Online, Equitable Access.

I. Introduction

The COVID-19 pandemic and its necessitation of a quick transition to online learning have incited an increased adoption of innovative methods for engineering students to engage with class material. One method is the remote laboratory where students leverage the Internet to access expensive hardware remotely. Still, although the pandemic has advanced these innovations, certain inequities persist which prevent all students from receiving a high-quality education. While opinions on equitable access from organizations and broader engineering fields have been studied since the pandemic began, this study looks at the student perspective on remote hardware and equitable access within electrical and computer engineering education in a post-pandemic era.

The Remote Hub Lab (RHLab) was founded at the University of Washington in response to the COVID-19 pandemic and the emergency shift to distance learning. Since the autumn of 2020, students enrolled in a junior-level course on digital design (EE 371) have been using the Remote Hub Lab to remotely access a network of hardware distributed between five universities: the University of Washington, the University of Michigan, Monash University in Malaysia, the Public University of Navarre UPNA in Spain, and the Federal University of Sao Paulo in Brazil. This hardware includes Field Programmable Gate Arrays (FPGAs) on DE1-SoC boards used with Quartus and ModelSim software.

In a recent study by Hussein and Wilson [1], student performance in an in-person offering of a digital design course (physical lab kits required) was compared to an online offering of the course (using the RHLab). The study showed that "students performed significantly better in terms of overall scores and analyze skills" in the online offering. The efficacy of remote labs as an avenue for distance learning in engineering education is not a novel concept, as evidenced by the Sloan Consortium in [2], but the pandemic revealed the link between remote resources and learning competencies within the engineering discipline.

Still, since the beginning of the pandemic in March 2020, new barriers to continuing and completing postsecondary education – including that of the engineering discipline – have been observed throughout the US [3]. A 2021 report from the Institute for Higher Education Policy (IHEP) found that, out of 1008 college student survey participants, only 73% reported having access to fast and reliable internet connections [4]. Moreover, barriers to accessing the Internet and course materials (such as device availability and Internet cost) disproportionately affect low-income households and Black and Latinx communities [4]. Across the US, those in underrepresented communities before the pandemic were disadvantaged further, as the pandemic severely complicated educational opportunities previously in reach [2]. Furthermore, the pandemic's lingering effect on learning may worsen achievement gaps between these communities and their more privileged counterparts if not actively combated [5]. This observation about the US is harrowing, especially when Internet access is now seen as a human right [6]. These post-pandemic developments must be considered when examining post-secondary engineering education.

In the post-covid-19 era, studies on remote labs' accessibility as an equitable solution and the accessibility's impact on the student experience become inevitable. In an ongoing effort to address equitable access to engineering education within the remote lab space, we seek to understand the student perspective on the remote lab experience.

II. Theoretical Framework

Understanding student perspectives on the remote lab (RHLab) experience through the lens of equity requires an evaluation of both pre- and post-pandemic perceptions of equitable access.

A. Equitable Access Before the COVID-19 Pandemic

Like most abstract concepts, equitable access does not have one uniform definition, even before the COVID-19 pandemic. Within online engineering education, for example, the Sloan Consortium in 2005 identified five pillars of high-quality online education: learning effectiveness, student satisfaction, faculty satisfaction, access, and cost-effectiveness [2]. More broadly, [7] in 2008 conceptualized equity in education to have two dimensions: fairness and inclusion. More recently in 2016, [8] defined "Engineering Education for All" to be "studies available for all those loving Engineering, without taking account of their social class and economical status." Key strategies for promoting equitable access include those focusing on students, teachers, and teaching methodology, synergies with the environment, and available resources, highlighting drivers of change like "open-access software and computing resources" and "virtual labs and online learning resources" [8].

B. Equitable Access After the COVID-19 Pandemic

Since the onset of the COVID-19 pandemic, equitable access to technology has become a prominent concern for students, families, educators, and governments alike.

In 2022, the International Society for Technology in Education defines equitable access as "Robust and reliable access to current and emerging technologies and digital resources, with connectivity for all students, including those with special needs" [9]. In 2021, the State Educational Technology Directors Association (USA) identified key measures by which certain states measure digital inequity: "Device age, replacement cycle, and appropriateness to learning needs" as well as "Internet Access data caps, upload and download speeds, and ability to support remote and blended learning models" [10]. In a review of leverageable technologies for STEM education, Amunga [11] determined cost, internet stability, speed, power connectivity, and stability as pertinent concerns regarding access. Transforming Education for Life pinpointed five components that must be addressed for equity in education to be achieved: affordability, accessibility, high quality, low barriers to entry or access, and ease of use [12]. Similarly, the Technology Alliance's Task Force in Washington state identified five recommended areas of action in future remote learning efforts: internet connectivity, learning devices, student learning and educator readiness, information technology support, and family communications [13].

Other studies have found physical presence on campus to be central to the student experience, although culture and environment can be found in the online context too [14]. Furthermore, even when Internet connectivity is available, students must have adequate digital literacy skills as well as a home environment and daily schedule that allow them to engage in online learning [4], [6].

Taken together, these modern perceptions of equitable access reflect the relevance of common factors to evaluate in the RHLab: its remote nature, affordability, learnability, usability, and responsiveness as well as the student's schedule, environment, device access, and prior digital literacy.

C. Framing This Study

Evaluating these various perceptions, we notice a lack of isolated input from the electrical and computer engineering student perspective on equitable access within the remote lab experience. For instance, [15] found key issues in general online engineering education (technical problems, learning/teaching challenges, and privacy and security concerns) by surveying more than 100 faculty and 600 students from six engineering departments at California State University. As opposed to largely institution-driven, non-engineering, or broad engineering evaluations of equitable access, this study focuses on the student perspective, seeking the opinions of those who have largely experienced online learning since 2020. Leveraging an initial survey, this study reports on factors that engineering students value when considering equitable access in remote labs.

III. Research Contribution

To gain insight into the aspects of equitable access deemed important by engineering students in a remote lab environment and the post-pandemic world, we conducted a preliminary survey of students taking a Design of Digital Circuits and Systems course at the University of Washington. This course required the use of the RHLab to complete coursework. The voluntary and anonymous survey was offered to 57 electrical and computer engineering students, garnering 29 distinct responses. Of the 29 responses, 28 had no prior remote hardware experience before the course. Despite the small and concentrated survey population, administering this initial survey is an essential step in improving the remote lab's accessibility and scalability for future courses as well as its commitment to equitable access for underrepresented communities.

A. Methods

The survey's goal was to evaluate student perspectives on key factors of the remote lab experience, both those shown in previous research and those advocated by the respondents themselves. Using a combination of the Likert scale, semantic differential scale, multiple-choice, and short/long/numerical free-response questions, the survey was divided into five sections and included twenty questions, engaging in thorough quantitative and qualitative analysis of responses. Table I details the question breakdown by order, format, and topic.

The survey's five sections are as follows: preliminary information, lab features, internet connectivity, hardware preferences, and feedback and insight. Among these sections, key results stem from the lab features (Q3-5) and feedback & insight (Q16-17, Q20) sections which focus on research-identified and student-mentioned factors of importance when considering equitable access in the remote lab.

TABLE I. 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 Free Response	Explanation of answer to Q1
Lab Features	Q3	Likert Scale	Level of agreement with identified factors of the Remote Hub Lab
	Q4	Long Answer Free Response	Explanation of answers to Q3
	Q5	Long Answer Free Response	Other helpful and/or challenging aspects of the Remote Hub Lab
Internet Connectivity	Q6	Multiple Choice	Frequency of Internet access on a normal day
	Q7	Multiple Choice	Frequency of dropped Internet connections
	Q8	Numerical Free Response	Internet Speed Test; Download Speed (Mbps)
	Q9	Numerical Free Response	Internet Speed Test; Upload Speed (Mbps)
	Q10	Numerical Free Response	Internet Speed Test; Latency (ms)
Hardware Preferences	Q11	Semantic Differential Scale	Willingness to share DE1_SoC lab kits
	Q12	Semantic Differential Scale	Willingness to access hardware only on campus in a physical lab
	Q13	Multiple Choice	Willingness to pay for a DE1_SoC if required for engineering coursework
	Q14	Multiple Choice	Willingness to pay for a DE1_SoC for personal projects and interviews
Feedback & Insight	Q15	Semantic Differential Scale	Evaluation of the Remote Hub Lab's accessibility
	Q16	Long Answer Free Response	Important factors when considering equitable access
	Q17	Long Answer Free Response	If/why answer to Q16 would change if asked pre-pandemic
	Q18	Multiple Choice	Willingness to be contacted again about remote lab experience
	Q19	Short Answer Free Response	Preferred email address if student answered "yes" to Q18
	Q20	Long Answer Free Response	Other thoughts and feedback about the remote lab experience

Whereas Q3 was quantifiable by the Likert scale, Q4-5, Q16-17, and Q20 were free-response. For simplicity, Q4-5 and Q20 were grouped as investigators of student-identified "Factors of the Remote Experience" (FREs), as opposed to Q3's research-identified FREs. Q16 and Q17 comprise another grouping that focuses on student-identified "Factors of Equitable Access" (FEAs). To qualitatively analyze these two groupings, two codebooks were used to identify recurring themes and their frequency of occurrence within each grouping of student responses. These codes and themes will be discussed in *Results and Findings*.

Other contextual results can be found in the preliminary information (Q1-2) and internet connectivity (Q6-10) sections which provide insight into the characteristics of the student survey population. The hardware preferences section (Q11-14) focused on student opinions regarding other options for engineering lab formats. Q15 explicitly gauged student perspectives on the general accessibility of the remote lab, and Q18-19 measured students' willingness to participate in subsequent research into remote lab accessibility and their contact information as applicable.

B. Results and Findings

a) Research-Identified FREs: Identifying eight key factors of remote labs based on prior research in the field (FREs), Q3 evaluated the students' level of agreement with statements that gauged the FREs' helpfulness for learning. Q3 took the form of a matrix question with eight Likert scale sub-statements, one for each FRE:

- The RHLab's *remote nature* (not needing to be in-person),
- The RHLab's *learnability* (after the first few uses)
- The RHLab's *usability* (throughout the academic quarter)
- The RHLab's *responsiveness* (not prone to lagging)
- The student's *prior digital literacy* (ability to learn software tools through experimentation and the Internet)
- The student's *access to electronic devices* (like computers that can access the remote lab)
- The student's *environment outside of class* (distraction-free space conducive to working in the remote lab for at least one hour at a time)
- The student's *schedule* (can work in the remote lab for at least 1 hour at a time).

The following is an example sub-statement (gauging the student schedule FRE): "My schedule allowed me to work with the remote lab for at least 1 hour at a time." Presented with "strongly disagree," "disagree," "neutral," "agree," and "strongly agree" as options, the students chose which best matched their opinion on each FRE's helpfulness for learning. Fig. 1 shows the students' effective ranking of research-identified FREs. Summing Q3's "strongly agree" and "agree" responses, we can see the students' ranking of research-identified FREs from highest to lowest importance:

- The Student's *Access to Electronic Devices* (26)
- The Student's *Environment Outside of Class* (24)
- The Student's *Schedule* and the RHLab's *Learnability* (23)

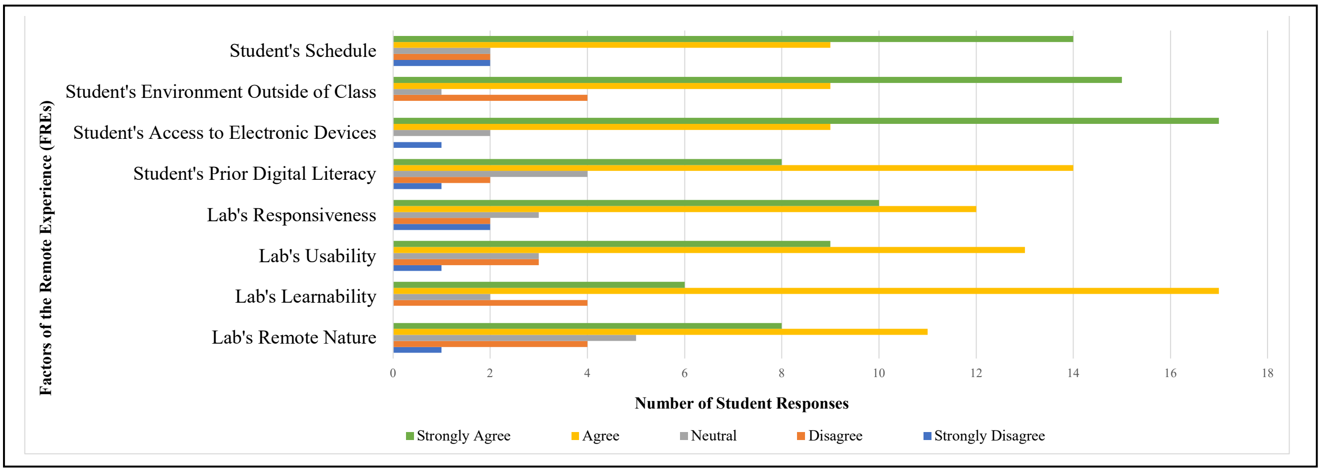

Fig. 1. Students' agreement with research-identified FREs' conduciveness to learning

- The Student's *Prior Digital Literacy*, the RHLab's *Responsiveness*, and the RHLab's *Usability* (22)
- The RHLab's *remote nature* (19).

To understand the students' stance on hardware *affordability* – another research-identified FRE – we asked the students about their willingness to pay for the DE1_SoC board for required coursework (Q13). The students were informed that a DE1_SoC board typically costs around $300 (USD) for each lab kit. The distribution of student responses to Q13 is shown in Fig. 2. Similarly, Q14 inquired about willingness to pay for a DE1_SoC for exploration and interview preparation, and the results are shown in Fig. 3.

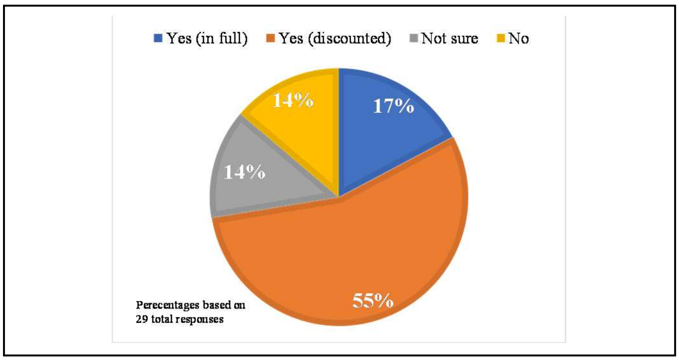

Fig. 2. Student willingness to pay for hardware (a DE1_SoC board) for required coursework

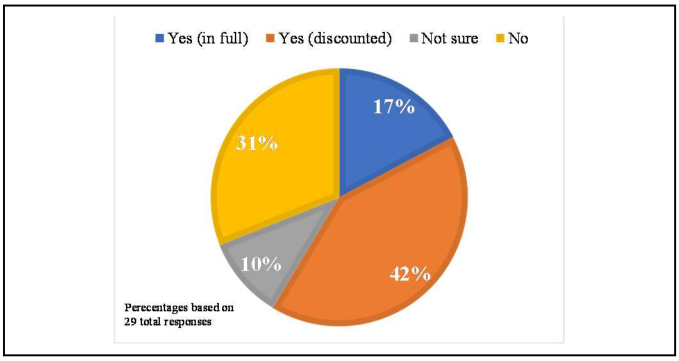

Fig. 3. Student willingness to pay for hardware (a DE1_SoC board) for exploration and interview preparation

Fig. 2 shows that most of the survey population (55%) indicated that they would be willing to pay if given a discount, and 28% demonstrated doubt or refusal to pay for the hardware. Fig 3 shows more people (31%) would not be willing to pay for the hardware for personal use at all. Not only does this demonstrate that affordability is an important FRE to a substantial number of students, but it also illustrates that having labs with equitable access for all students means being prepared to support them through 1) subsidized or free physical hardware for school use or 2) other alternatives like the RHLab which provide hardware access beyond school requirements.

Other affordability options are explored in Q11 and Q12. When asked to rate their willingness to share lab kits with one partner from 1 ("I would rather not") to 5 ("I would be very willing"), 48% chose 1 or 2, indicating a strong aversion to sharing lab kits as shown in Fig. 4. Similarly, Q12 indicated that 48% of respondents had a strong aversion to going to campus for lab access (in the case that institutions choose to address hardware inventory limitations or damage prevention with such a requirement), as shown in Fig. 5.

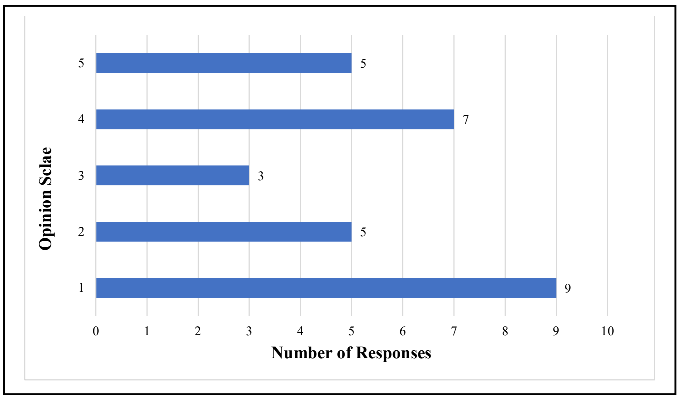

Fig. 4. Student willingness to share lab kits, measured from 1-5 with 1 indicating "I'd Rather Not" and 5 indicating "I'd Be Very Willing"

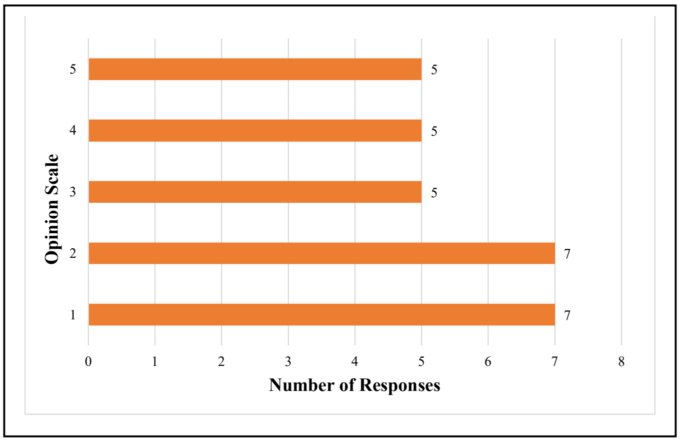

Fig. 5. Student willingness to go to campus for lab access, measured from 1-5 with 1 indicating "I'd Rather Not" and 5 indicating "I'd Be Very Willing"

From these results, we found that the surveyed students had mixed opinions regarding affordability as an FRE. Approximately half of the respondents indicated neutrality or a willingness to share lab kits and to physically travel to a university campus to gain lab access. At the same time, the other half of the respondents do not wish to share lab kits or travel to a physical lab just to gain the ability to complete their schoolwork. This range of opinions raises important questions as to how institutions will accommodate varied preferences for engineering education in the future.

b) Student-Identified-FREs: When asked about factors (not mentioned in Q3 or the survey as a whole) that they deem important when considering their remote lab experience, the students provided freeform insight. To identify trends from these responses, we leveraged a codebook to analyze student responses. The codes and their associated phrases or mentions from Q4, Q5, and Q20 are listed in Table II. Moreover, the frequency of occurrences of each student-identified FRE code is documented in Fig. 6.

Of the student-identified FREs, specific factors highlighted by the survey results include the following:

- The RHLab's *Web Interface Design*
- The RHLab's *Convenience*
- The RHLab's *Ease of use*.

TABLE II. FRE CODEBOOK (Q4, Q5, AND Q20)

Code	*Associated Phrases, Mentions, and Ideas*
Overall Positive Experience	Works well, Awesome, Amazingly, Few problems, Liked, Worked fine, Caught errors not found in Quartus, Great, 10/10 experience, Learned just as much with remote as physical, Should scale to other classes / future offerings, Good given COVID, Effective alternative
Preference for Remote Hardware	Preferred the remote lab experience to the physical one, So much nicer than when I used the actual hardware, Much easier to work with than an in-person FPGA
Explicit Mention of "Accessibility"	(Self-Explanatory)
Ease of Use	Easy, Ease, Easy-to-use, Easy to learn, Easy to understand
Convenience	Save time and hassle, Convenient, Can be accessed everywhere, No need for shipping, Flexible, Helpful, No damage concerns, Avoid set up of hardware components
Overall Negative Experience	Remote labs should not scale to other classes or future offerings, unpleasant experience, wanted lab partner support
Preference for Both Physical and Remote Options	University can or should provide both physical and remote options, hesitancy using remote hardware in the future
Preference for Physical Hardware	Prefer to have the actual hands-on lab kit, physical hardware provides a better experience, online option takes away from or limits learning as opposed to physical hardware
Connection Issues	Offline, Lag, Delay compared to normal use
Web Interface Design Complaints	Discrepancy between FPGA boards, 3-minute time limit, Inconsistent Results, Buggy, Faulty, Can't press multiple keys at a time, Compilation takes too long, Compilation is different than on Quartus, Confusing Breadboard GPIO

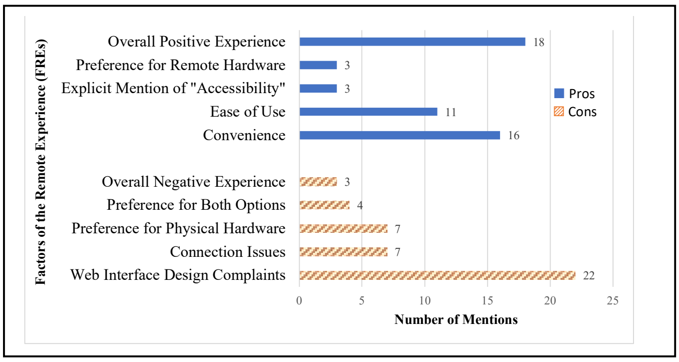

Fig. 6. Student-mentioned FREs vs. number of mentions in free responses

Despite web interface design complaints specific to the University of Washington's RHLab, grouping the FRE codes into pros and cons demonstrates an overall positive student experience, as there exists stronger agreement with the FREs of convenience and ease of use rather than with other cons.

c) Student-Identified FEAs: Another codebook was leveraged for Q16 and Q17 which sought to understand the factors students deem important when considering equitable access. Table III lists the codes for Q16 and Q17, and Fig. 7 depicts the results from coding the student-identified FEAs.

TABLE III. FEA CODEBOOK (Q16 AND Q17)

Code	*Associated Phrases, Mentions, and Ideas*
Freedom of Choice	Option to use physical hardware as well as remote hardware
Fair Access Within the Class	Queue times and rules, Time allowed with hardware, Technical support/educational support
Affordability	Free, Cost, Lab fee
Internet Quality	High speed, Responsive UI, Reliability, Computing ability, Strength
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

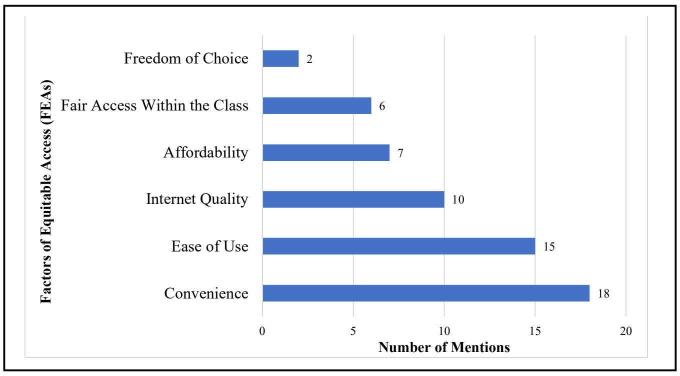

Fig. 7. Student-mentioned FEAs vs. number of mentions in free responses

From Fig. 7, we observe the following FEAs as key factors of importance to the survey population: *convenience*, *ease of use*, *internet quality*, *affordability*, *fair access within the class*, and *freedom of choice*. These FEAs echo the themes in both research and student-identified FREs. Clear connections include the student-identified FREs of *convenience* and *ease of use* and the research-identified FRE of *affordability*. Similarly, *fair access within the class* refers to certain *web design complaints* specific to the RHLab, such as the allowed session time per student with the remote hardware. Finally, *freedom of choice* reflects the various preferences of students in Q4, Q5, and Q20 regarding engineering lab format (remote hardware vs. physical hardware).

Q17 provided another opportunity for students to expand on their Q16 answers, and 21% of students indicated that their answers would have changed if they were asked Q16 before the pandemic. Because more than one-fifth of the students indicated as such, Q17 demonstrates how these FEAs became more apparent to certain respondents after the COVID-19 pandemic.

d) Other Student Opinions and Preferences: In addition to examining FREs and FEAs, this study also measured the student perspective on the RHLab as a whole. Q15 explicitly asked students about their opinion on the accessibility of the RHLab. The results are depicted in Fig. 8.

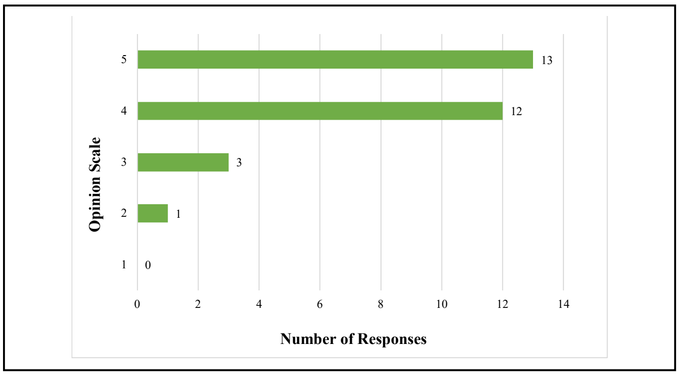

Fig. 8. Student opinion on the accessibility of the RHLab. The Opinion Scale is measured from 1-5, with 1 indicating "Very Inaccessible" and 5 indicating "Very Accessible"

Because 86% of respondents chose 4 or 5 as their answer, we surmise that – despite room for improvement as indicated by Q4, Q5, and Q20 – overall, students experienced equitable access in the RHLab.

After the eight Likert scale sub-questions regarding FREs, Q3 also measured 1) student agreement with a statement that remote labs should be incorporated in other college courses and 2) student agreement with a statement of personal confidence in operating remote hardware in the future. The results of these two sub-questions are depicted in Fig. 9 and Fig. 10, respectively.

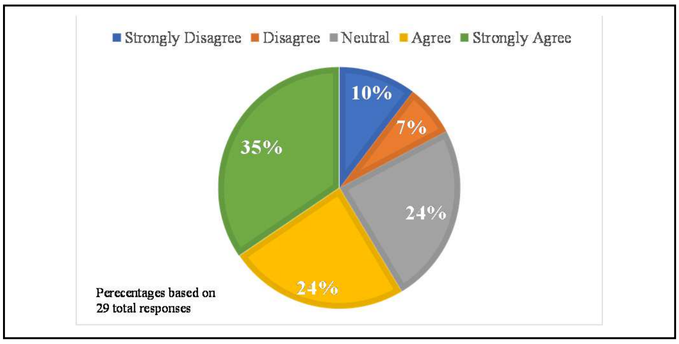

Fig. 9. Student agreement with the statement, "Being able to access hardware remotely should be implemented in more university courses."

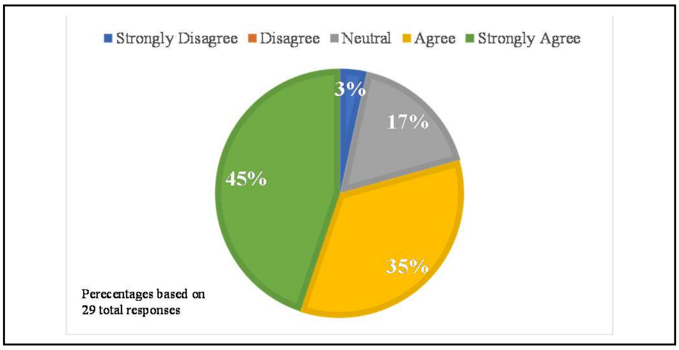

Fig. 10. Student agreement with the statement, "I am confident that I could operate remote hardware in the future."

e) Other Student Data: The survey also measured contextual data about the student responders concerning their Internet use. Q6 inquired about the typical time spent on the Internet on a normal day, whether for schoolwork or otherwise. As depicted in Fig. 11, the majority of the class spends more than eight hours on the Internet daily, whether for schoolwork or personal use.

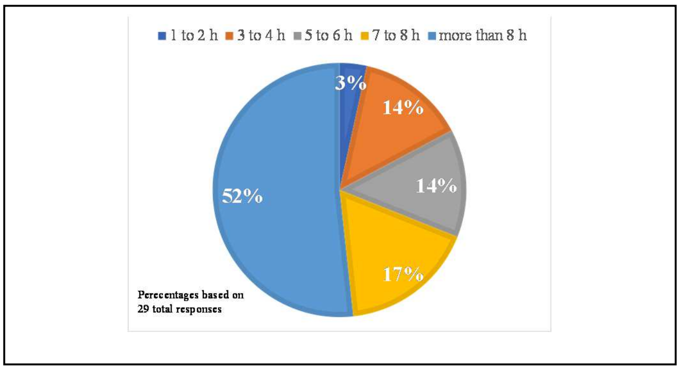

Fig. 11. Time students spend using the Internet per day (in hours)

We also found that, when asked about the frequency of dropped Internet connections they experienced (Q7), most of our survey population reported infrequent dropped connections, with only 14% reporting multiple dropped connections per week or day. Fig. 12 illustrates the complete results of Q7.

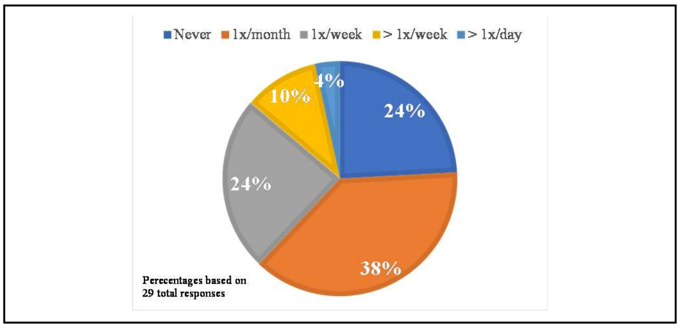

Fig. 12. Frequency of dropped Internet connections experienced by the students

Given the respondents' sustained amount of time devoted to Internet use per day and the infrequency of their dropped connections, we surmise that our concentrated survey population of 29 college engineering students generally has a strong Internet connection. This observation is corroborated by the student's answers to Q8-10. Before answering Q8-10, we asked students to perform an Internet speed test and report their download speed (Mbps), upload speed (Mbps), and latency (ms) as numerical free-response. The result was an average download speed of 173.44 Mbps, an average upload speed of 99.64 Mbps, and an average latency of 10.86 ms. Taken together, this contextual data about our survey respondents illuminates key implications and limitations of this study.

C. Discussion: Implications and Limitations

a) Implications: Overall, research-identified FREs deemed most important by the surveyed engineering students include the following:

- The Student's *Access to Electronic Devices*
- The Student's *Environment Outside of Class*
- The Student's *Schedule*
- The RHLab's *Learnability*

The students also identified the following FREs in their freeform responses:

- The RHLab's *Overall Positive Experience*
- The RHLab's *Convenience*
- The RHLab's *Web Interface Design.*

Finally, the students identified FEAs which resonated with similar themes including the following:

- *Convenience*
- *Ease of Use*
- *Internet Quality*
- *Affordability*
- *Fair Access Within the Class*
- *Freedom of Choice*

The survey also revealed insight into some students' negative experiences in the RHLab and why they may prefer working with physical hardware. It is important to note that those who indicated such opinions also indicated a preference for hands-on learning, and despite this preference, they believed the remote lab aptly met the demands of distance learning during the pandemic. This reflects the general appreciation of students for the remote lab, even when some experience a distaste for online learning or a "phobia of losing internet connectivity" [16]. Though these experiences are not common to all respondents, the recurring suggestion of having both physical and remote hardware options put forth another insight for RHLab to consider, as supported by [17].

b) Limitations: It is important to note that survey results were based on responses from 29 engineering students taking an electrical and computer engineering course at a well-funded institution. In particular, some data regarding FREs and FEAs gauged student opinions using freeform questions. Responses were of varying length, with some students giving terse responses and others elaborating on both pros and cons. Moreover, the research context of this survey was largely based in the US, and experiences may differ in other countries' cultural contexts. The experiences of the surveyed students may not be representative of other students in diverse, marginalized, and underserved communities, due to the concentration of respondents from one class at one institution. For example, 72% of respondents would be willing to pay in full for the hardware if required by the course. Furthermore, without analyzing the survey results for unusual outliers, the average Internet download speed of respondents (173.44 Mbps) was high compared to the national average (146.17 Mbps) [18], suggesting that other FREs and FEAs may have been highlighted for more disadvantaged students.

However, although the survey detailed in this paper does not include traditional demographical questions, the correlation between the questions asked like Q7 (frequency of dropped Internet connections), Q13 (willingness to pay for DE1_SoC if required for engineering coursework), and Q15 (evaluation of the Remote Lab's accessibility) offer a window into what certain groups of students prefer relative to the quality of their Internet access. For example, of the 38% of survey respondents who reported experiencing dropped internet connections once a week or more, 18% also indicated "no" or "not sure" regarding their willingness to pay for the hardware had it been required for engineering coursework. Moreover, of the 38% of survey respondents who reported experiencing dropped internet connections once a week or more, the majority (72%) rated the RHLab's accessibility as 4's or 5's (with 1 being "very inaccessible" and 5 being "very accessible"), indicating how remote labs may have a long-term impact on the quality of students' learning experience.

IV. Conclusion and Future Work

Based on a voluntary and anonymous survey of college students who took an electrical and computer engineering course using a remote lab of FPGA hardware, this study found that the students considered the following to be key unique factors regarding equitable access and the remote lab experience (in no particular order):

- The Student's *Access to Electronic Devices*
- The Student's *Environment Outside of Class*
- The Student's *Schedule*
- The Student's *Internet Quality*
- The Lab's *Learnability*
- The Lab's *Web Interface Design*
- The Lab's *Convenience*
- The Lab's *Ease of Use*.
- The Lab's *Affordability*
- The Lab's Provision of *Fair Access Within the Class*
- The Lab's Accommodation of *Freedom of Choice*
- The Lab's *Overall Positive Experience.*

While these results may not be sufficient to arrive at a conclusive summary of remote experience factors and equitable access factors deemed important by all engineering students, the FREs and FEAs identified by this study provide important insight into the student perspective in a post-pandemic era. Whereas early research regarding post-pandemic opinions largely involves broad studies about online education (not focused on engineering) or institutional perspectives about online engineering education (not focused on students or the remote lab aspect), this study presents an understanding of the student experience.

To improve the accessibility of the RHLab and to further study the student perspective on equitable access in remote lab spaces, ongoing and future work of the RHLab is twofold: 1) reach out to partner institutions and community colleges in underserved communities with a similar survey geared toward a larger and more diverse population to build on the findings of this study, and 2) create and share an introductory digital logic curriculum which helps students learn how to use the remote lab. It is the goal of the RHLab that both the introductory lab curriculum and future iterations of this study's survey will reveal more insight into achieving equitable access to engineering education by leveraging the student perspective in a post-pandemic era.

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