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Fostering an Inclusive Community Among Electrical Engineering Students with Mixed-Reality Technologies at a Hispanic-Serving Institution

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Fostering an Inclusive Community Among Electrical and Computer Engineering Students with Mixed-Reality Technologies at a Hispanic-Serving Institution

Abstract

Educators have consistently sought resources to enhance social learning experiences that support diverse student populations. Research shows that a sense of belonging significantly impacts students' learning outcomes, particularly after the shift to hybrid learning models following COVID-19. While the hybrid model has allowed students to continue their education remotely, it has introduced challenges in fostering a sense of belonging within the learning community. We employ a qualitative approach, including interviews and participatory design methods, to examine the experiences of students in the Electrical and Computer Engineering (ECE) Department at a Hispanic Serving Institution. We focused on existing learning community issues within the hybrid learning environment. We employ a sense of belonging framework to analyze students' learning experience, challenges, and needs in their academic pathways. Our findings reveal the need to foster student belonging to strengthen the ECE learning community. We propose employing mixed reality technologies, known for enabling collaboration across different environments, to address students' lacking sense of belonging.

1 Introduction

Enrollment statistics at a Hispanic-Serving Institution (HSI) reveal that the number of students enrolled in Electrical and Computer Engineering (ECE) graduate studies is considerably lower than those in undergraduate studies. The institution enrolls a large Latinx and multiculturally diverse student population [1]. The socio-economic conditions and educational inequalities in the surrounding area pose a challenge for this minority population to pursue graduate studies [2]. After the COVID-19 pandemic, there has been a notable shift towards hybrid and blended learning models [3]. These approaches offer a combination of scheduled class sessions and self-paced classwork [4], providing students greater flexibility and agency in their learning. This is particularly beneficial for students who may face socio-economic or family-related challenges, as it allows them to adapt their learning to their individual circumstances. However, remote learning approaches and technologies do not necessarily support the formation of learning communities at the level necessary to support students in their pursuit of undergraduate and graduate studies.

Our long-term research agenda focuses on enhancing social learning among students, teaching assistants, and instructors, while also promoting community formation through new remote

learning technologies in the context of the ECE Department at this HSI. We also seek to enhance students' sense of belonging to their academic program and college. For the purpose of this study, sense of belonging means students' perceived social support on campus, a feeling or sensation of community, the experience of feeling cared, about, accepted, and respected, and important to a group or others on campus (e.g., faculty, peers) [5]. In particular, we focus on mixed-reality (MR) based approaches to create online spaces where both on-campus and remote learners can engage socially and academically. While mixed-reality can take on many forms, significant work has found that combining augmented and virtual reality (VR) technologies can be used to create digital environments that effectively support collaborative activities [6]. Two research questions guide our present work:

- What are the existing learning community issues among ECE students at this particular HSI?
- How can these problems be addressed through a mixed-reality (MR) learning community platform?

To begin to answer these questions, we take a multiple-sources qualitative research approach. First, we conducted an interview based study aimed at understanding the first research question. In the second study, we conducted a series of participatory design (PD) sessions with students to begin to develop designs for a mixed-reality space that addresses the community challenges faced by students. We conducted an inductive qualitative analysis and triangulated the data from both sources.

In the following, we further present the context in which this research was conducted, related work, and discuss the methods and findings of both studies. Finally, we discuss the implications of the findings and future work in terms of future learning community development through mixed-reality learning community spaces at this HSI.

1.1 Context of the project

This work is done in the context of a Hispanic-Serving Institution (HSI) that enrolls a large Latinx and multicultural student population including 58.3% Hispanic, 26.1% whites, 5.4% nonresident aliens, and 9.2% other minorities. A large number of the Latinx students come from the county in which this HSI is located. This county houses 37 communities known as "Colonias", which are defined as impoverished settlements on agriculturally valueless land [citation ommitted for anonymity]. These communities lack access to basic infrastructure, such as paved roadways, clean water, and electricity service.

Figure 1 illustrates the demographic breakdown of student members of the ECE department at this HSI. While there is significant diversity in terms of student ethnicity, there are significant gender inequalities. The institution and the department serves a significant number of students and families who must overcome socio-economic barriers and educational inequalities. Many of these students commute, work full-time jobs, and/or attend remotely due to these conditions. Such marginalization calls for improving the on campus climate and practices to instill in students a stronger sense of belonging [5]. This research is aimed at creating learning environments for

these vulnerable and at-risk students who may drop-out due to feeling that they do not belong and are not welcome in the engineering learning community.

2 Prior and Related Work

This section explores a theoretical framework for sense of belonging among college students [7], and discusses the core elements that influences the overall sense of belonging of learners' community. It also provides a brief overview of the existing research and literature on Virtual Reality (VR), Mixed Reality (MR), and Augmented Reality (AR) in educational settings. We discuss the features, benefits, and limitations of online learning environments and highlights how these technologies can help support learning communities. Additionally, we examine some studies that explore the social impacts of these technologies in educational contexts, such as fostering a sense of belonging.

2.1 Students' Sense of Belonging in Higher Education

Sense of belonging has been identified as "a universal and fundamental human motivation" in psychology [8]. Eccles and Midgley applied the concept of belonging to suggest that students' sense of fitting within their educational environment can influence their perception of whether they can succeed in it [9]. Nationwide, institutions seek to promote positive changes among underrepresented students, particularly, to connect students with mentors/role models, and

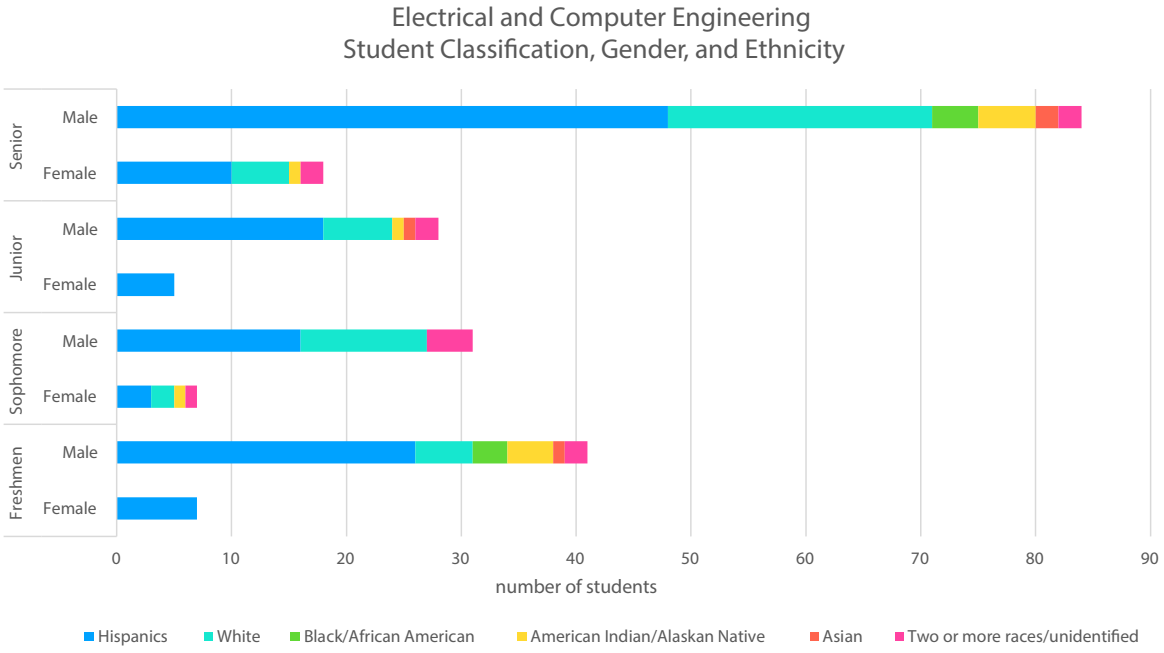

Figure 1: Student gender and ethnicity by grade classification in ECE. Data was aggregated from the HSI's Office of Institutional Analysis for the 2021-2022 academic year.

increase their influence in the learning process and their success [10, 11]. However, research has found that a lack of sense of belonging is a determinant factor in a student's decision to leave engineering [12]. The relationships a student develops with their peers, teachers, and faculty can affect that sense, influencing student performance, well-being, and the decision to stay/leave their engineering program [13, 12]. The students who appear to have greater difficulty with their sense of belonging are those who are often underrepresented in the STEM/Engineering field(s), such as women or students with minoritized racial/ethnic identities [10, 12].

Sense of belonging is also a critical factor in establishing sense of community [14]. So given the importance of promoting learning communities in higher education, especially engineering, it is essential to establish inclusive learning environments that that benefit students' sense of belonging [11]. Students oftentimes feel that if they are working with someone, especially staff, rather than for them, they feel a greater sense of belonging [15]. Particularly, when someone from the staff listened and worked with them, students' college experience was enhanced in a way that allowed them to gain the most from their degree program.

In this sense, Strayhorn identified seven core elements of sense of belonging [7], which he identifies as critical to the learning experiences of college students. We review these below.

- *Sense of belonging is a basic human need* that is deeply rooted in sense of connectedness, membership, and belonging in college. It is a part of the motivational hierarchy and connection to knowledge generation and understanding. Thus, college students, sense of belonging must be satisfied before any other high order needs such as knowledge and self actualization.
- *Sense of belonging is a fundamental motive to drive human behavior*, linked to individuals' need to belong to something important and be considered, seen, and appreciated.
- *Sense of belonging takes on heightened importance in certain contexts, times, and populations* and results in a shared sense of socially constructed meaning that provides a sense of security or relatedness.
- *Sense of belonging is related to mattering* and is linked to feelings of being needed or wanted.
- *Sense of belonging intersects with and affects one's identity*. Additionally, true belonging requires acceptance, authenticity, and transparency of self to be part of a community.
- *Sense of belonging engenders other positive outcomes* such as higher achievement, engagement, happiness, and well-being.
- *Sense of belonging must be satisfied as conditions change.* The susceptibility and malleability of sense of belonging necessitates being mindful of its vulnerability in peoples' lives and decisions.

These core elements represent a basic set of requirements for supportive learning environments. However, these elements can vary in their influence from person to person. Strayhorn suggests that sense of belonging is not static and may change over time. This highlights the need for carefully designed strategies that address these basic needs consistently and sustainably over the long term [7]. In this study, we apply Strayhorn's framework to analyze our findings from the

conducted interviews and PD sessions. In the discussion, we further explore how MR spaces can offer a supportive and inclusive learning environment at this Hispanic-Serving Institution (HSI).

2.2 Virtual Learning Environments

Virtual Learning Environments (VLE) often refers to software solutions that facilitate online education by offering tools for attending classes, accessing study materials, delivering content, and tracking teaching progress across different locations and time zones. Dillenbourg et al. [16] argued that VLE is not simply a trendy phrase used to describe educational software solutions. Instead, they define VLEs as planned spaces, either informational or social, where educational interactions happen not only as a form of distance learning but also to improve activities in a class. In VLEs, students play an active role in constructing the virtual space that can be represented in various forms, ranging from text-based platforms to fully immersive 3D worlds. VLEs bring together different technologies and pedagogical approaches, and they can coexist with physical learning environments [16].

O'Leary et al. [17], identified features of VLEs that positively impact student learning experiences, e.g., communication between tutors and students, self-assessment and summative assessment, delivery of learning resources and materials, and shared work group areas. Similarly, Bri et al. [18], analyzed the top three collaborative and asynchronous VLEs in the market at the time, Moodle/Blackboard, Sakai, and WebCT, and compared the list of features provided by each. They also surveyed their popularity among the students and identified which universities use which platforms.

However, there has recently been a more critical view of the effects of VLEs. For example, Dung et al. [19] found that VLEs could lead to lack of student social skills and emergence of digital divisions. Within the context of online learning during the COVID-19 pandemic, Caprara and Caprara [20] expressed doubts over students' ability to sustain mental health during purely online learning. They identified synchronous and face-to-face contact as having significant positive influence.

The impacts and features identified in these works align with the findings from both the interview and participatory design studies, including interaction modalities, shared working and social spaces, and fostering community support for students. In future work, we aim to address some of the pitfalls of existing VLEs through the design and integration of collaborative learning spaces.

2.3 Mixed Reality

Mixed reality (MR) was popularly introduced in 1994 in the Reality-Virtuality Continuum conceptual framework [21], with MR on a center point between total reality and total virtual reality as depicted in Figure 2. Augmented Reality (AR) was in between total Reality and MR whereas Augmented Virtuality (AV), lies in between MR and total immersion. Since then, MR has been conceptualized by people with their own perceptions and mental models and thus has a variation of definition even though it is a single term. To address this, Speicher et al. [6] surveyed

papers and elicited responses to the questionnaires answered by MR experts industry and academia to find and categorize the definitions of MR into six broad categories. They found these to be MR as Reality-Virtuality Continuum, MR as a synonym for AR, MR as a combination of AR and VR, MR as a strong AR with a better understanding of the environment, MR as a type of collaboration where AR/VR systems are used to facilitate to collaborate users among different systems, MR as an alignment of environment of two or more distinct environments. In the present work, our conceptualization primarily aligns with these last two definitions. In particular, we envision MR learning environments as collaborative spaces that span the boundaries of traditional campuses and online learning environments.

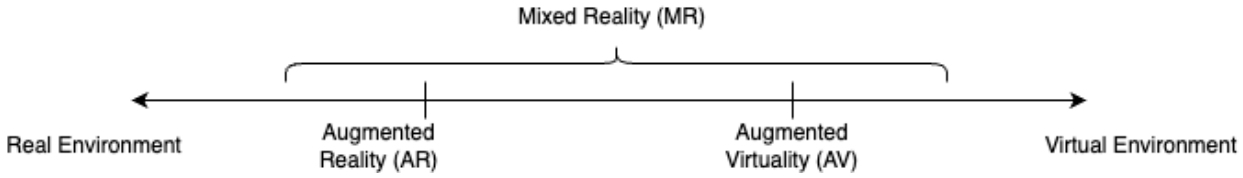

Figure 2: Milgram et al., Conceptual Framework of Reality-Virtuality Continuum [21]

2.4 Mixed Reality, Virtual Reality, and Augmented Reality in Higher Education

Recent literature in higher education has shown that MR techniques hold promising role for enhancing learning experience. However, their effectiveness may depend on factors such as the students' age and the instructional methods employed [22]. Researchers also found MR to be a particularly effective teaching method when used to visualize conceptual models and designs [23, 24]. Additionally, the application of MR tools may effectively personalize instruction in large classes [24]. Saidin et al. [25] found that using AR in academic settings solves many problems such as interesting students in science subjects and teaching abstract concepts through visualization. Tzima et al. [26] conducted qualitative studies of education AR technologies in suburban and rural regions of North-Western Greece. They found that while AR can be potentially effective teaching tool, appropriate changes in curriculum and pedagogy must be made. MR, AR, and VR [27, 28] based approaches have also been found to be particularly effective teaching modalities in the medical fields, where they effectively support teaching topics such as anatomy and surgical techniques. Studer et al. [29] examined the use of VR environments for training machinists.

Since MR tools can adapt based on the class material and/or the students' need(s)/knowledge level, they can help students successfully learn the material through personalized instruction that is not typical in larger classes. In this work, we consider how mixed reality can be used to support not only teaching and learning activities but also fostering learning communities through social activities.

3 Study Participants

Student participants represented a diverse group of undergraduate and graduate student members of the ECE community. Participants were recruited through informal information sessions that were advertised via departmental email lists and flyers. Nine total students participated, five in the interview study and seven in the Participatory Design Study. Three of these students participated in both studies. Of these nine students, six students identified as Hispanic while three identified as non-Hispanic. One of the recruited student was a woman, while the others were men. The study received IRB approval. Two different consent forms were used: one for the interviews and another for the participatory design sessions.

4 Interviews

Interviews are the most common tool for data collection in qualitative research. The interviews are "guided conversations" [30] used to gather information for a qualitative inquiry. The importance lies in the process of interviewing in the sense of "getting words to fly" [31]. To provide the appropriate environment and develop the skills necessary to make participants expressing their values, concerns, and experiences, researchers need to know themselves and learn to improve continuously their interview's skills [31]. One key element is the neutrality of the researcher in the interview process. In other words, the researcher should not influence and shape the responses of participants [32]. Furthermore, Erlandson et al. [33] noted the dialogical and interactive component in interviewing with a naturalistic approach, which for Lincoln and Guba [34] included discussing current events and circumstances, past experiences, and even future plans.

4.1 Data Collection and Analysis

Five students participated and shared their academic experiences. Students were asked to talk about their overall experience in college, challenges faced, use of technology, and recommendations to improve academics. Interviews lasted on average 30 minutes and took place at one of the researcher's offices. Students were asked to select pseudonyms to be used in the Findings section. The analysis of data consisted of transcribing the interviews verbatim and using Dedoose to assist with the analysis. The transcriptions were added to Dedoose, which the researchers read several times to identify units of information. The data unitization followed the creation of themes and categories using comparative techniques and deductive analysis [34]. In this last phase of the analysis, the researchers worked to make the information explicit guided by the research questions.

5 Participatory Design

The concept of participatory design (PD) originated in Scandinavia as an effort to empower labor unions, as a method of deciding on the application and workflow of new technologies in their workplaces [35]. In order to prioritize the needs and design goals of participants engaging with intersections of diverse identities, PD has been widely applied as a user-centered design method driven by the participants to create technologies and systems that empower those diverse

populations [36]. PD challenges conventional beliefs and assumptions about the role of technology in workplaces, communities, social institutions, and other environments. It emphasizes people when designing technology, prioritizes the improvement of people's working conditions over the application of cutting-edge technology [37]. Here we present a series of PD workshop sessions that we conducted to explore the needs and social contexts of the ECE learning community at this HSI.

5.1 Data Collection and Analysis

The data collected during the participatory design sessions included audio-visual recordings, paper-based design prototypes, and feedback forms. All the data were securely stored on a password protected private file server, accessible only to the researchers involved in this study. Participants in these sessions were assigned pseudonyms selected by the research team for reference within this paper. The audio recordings were transcribed using Otter.ai [38] with one of our researchers simultaneously listening to ensure accuracy. We used the Atlas.ti [39] qualitative analysis tool to identify the emergent themes in the collected data. We applied deductive approach of qualitative analysis [34] and minimized bias by merging the analysis from two researchers independently.

5.2 Sessions

We held a total of four sessions, including one pre-workshop session and three PD sessions. The pre-workshop session was used to recruit and inform potential participants on the content of the upcoming PD sessions. This session allowed potential participants to get to know one-another and the designer-researcher team through playing board games as an ice-breaking activity.

The remaining PD sessions began by clearly outlining participants' rights and obtaining individual informed consent. Participants who attended these sessions were provided 40 USD monetary compensation in Amazon gift cards for each session and were supplied food and beverages during the sessions. Participants were afforded the ability to request accommodations.

Seven participants attended PD session 1, in which participants were split into two groups, with two researchers participating in each group. Group 1 performed a storyboarding activity in which they brainstormed an academic issue and discussed different approaches to resolving this issue based on their unique backgrounds. Group 2 participated in a guided discussion led by researchers on the perceived issues within the local ECE community of students and instructors.

Three participants attended PD session 2, in which the research team summarized the issues identified within the first PD session, then guided a discussion on how participants would envision MR being used as a tool to address these issues. Participants then created low-fidelity prototypes [40] based on this discussion. During this session, to orient participants' design efforts, we briefly discussed the concept of MR [21] and six popularly used definitions of MR [6] to the participants.

The designer-research team synthesized the results of sessions 1 and 2, specifically focusing on the needs of ECE students for both social and academic activities that encourage collaboration, and created fictional scenarios for laboratory and social activities that required teamwork in both

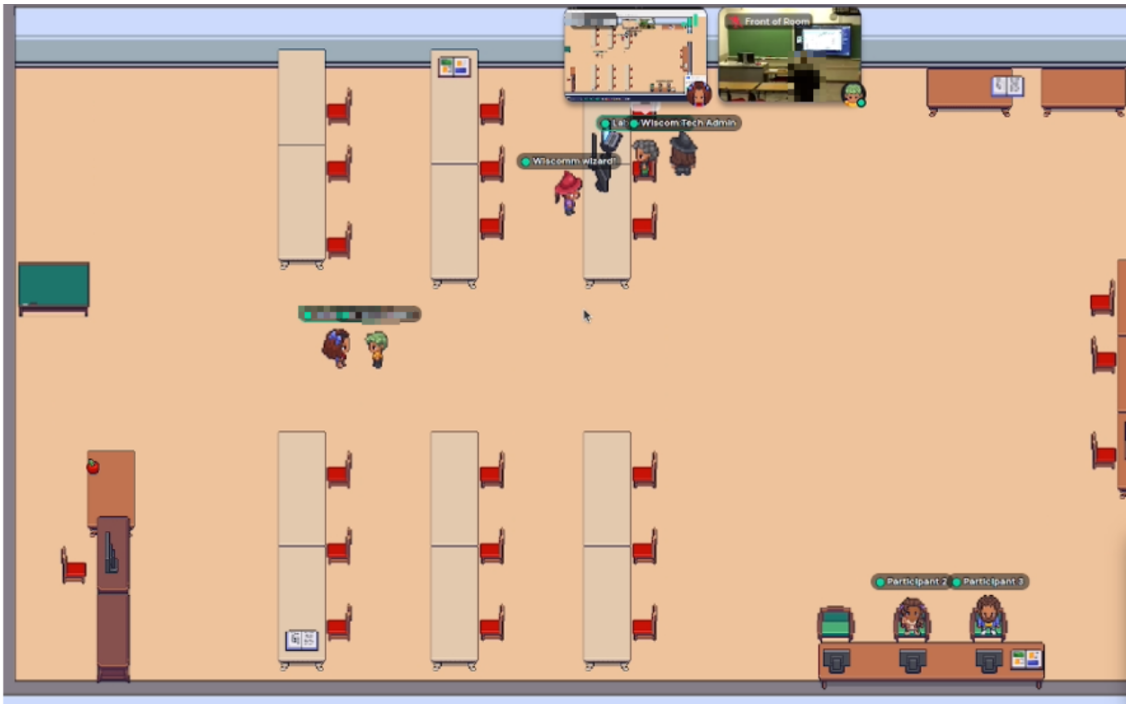

Figure 3: Screenshot of participants using the prototype MR system. A virtual classroom was created in Gather.town based on the classroom in which session 3 took place. Both remote and in-person students' presence is represented by virtual avatars.

in-person and online settings (see Figure 3). The team also constructed a prototype MR system using off the shelf components, including components like Gather.town [41], physical and digital simulations of laboratory equipment, and digital whiteboards. Three participants attended Session 3. Using the prepared scenarios and prototypes, students participated in role-play of an ECE laboratory activity (see Figure 4) and a social activity involving Pictionary. At the end of the session, participants shared their positive feedback on both activities in group discussion and feedback forms.

6 Findings

Our analysis aims to answer the research questions outlined in the introduction section. The themes identified in the collected data not only correspond with these questions but also highlights students' expectations within the ECE's learning environment, which are more fundamental requirements. There are eight themes identified in this study named as: student perspective on academic and social aspects, limited sense of community in academic settings, motivation and emotional supported needed, search for common communication spaces, need for synchronous and asynchronous communication systems, design preferences of MR learning spaces, and types of activities to be supported in MR.

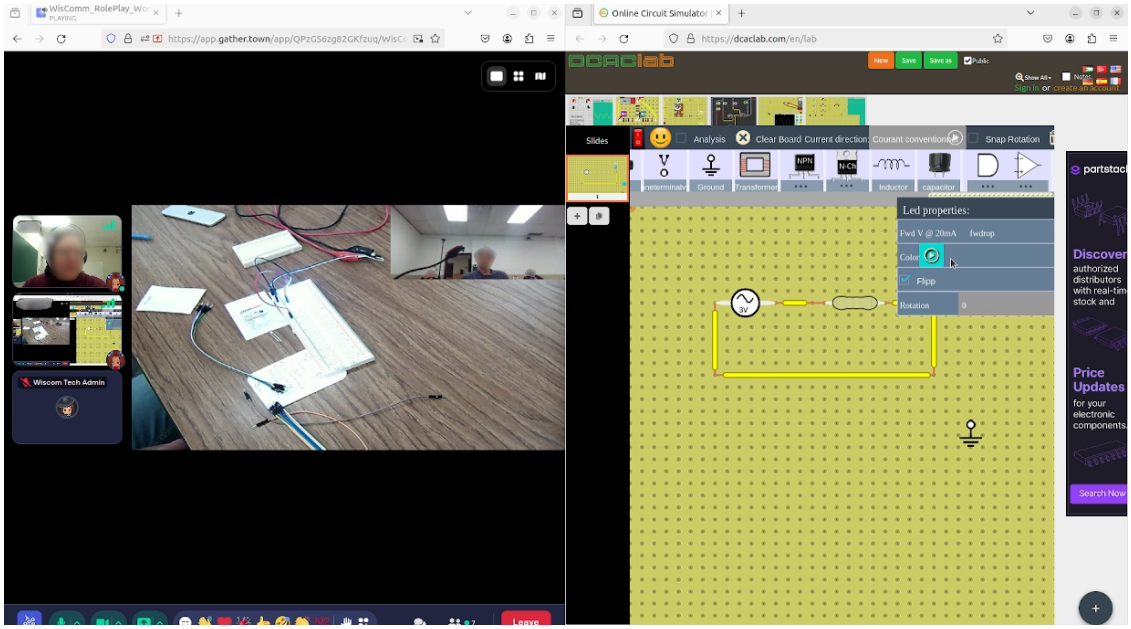

Figure 4: Remote participant's view of student participants engaging in an simulated laboratory scenario using a MR prototype.

6.1 Student Perspective on Academic and Social Aspects

This section includes information collected through the interviews. Data collected during the interviews helped answer the research questions, in particular, students discussed learning issues addressing educational and social gaps.

Students expressed different situations and aspects they consider problematic in their engineering programs. First, there was a feeling that nobody was paying attention to students' needs and that daily situation created a culture of silence among students. A veteran engineering student mentioned,

> *There's a culture here where people don't like to say anything when something's wrong and I've been screaming since I've gotten here.* Steve

This situation can generate other similar behaviors among the engineering student body and one of them is how students perceive the laboratory activities, where students should be applying what they are learning in their courses. A master's student in ECE vented,

> *Not like engineering classes can show you the theory, but they don't show you a lot of the real world applications or the labs are not basic on real world applications.* Juan

A few students commented on the lack of connection between course content and the laboratory practices. Either courses and labs were not connected or the laboratory practices had not been updated in a long time, generating in students a sense of wasting their time with laboratory assignments. Another comment was related to the overwhelming workload that engineering students have to spend in extra-curricular activities and programs, he revealed,

> *How do you get engineering students who are already spending way too much time outside of the classroom and the lecture hall studying to give up even more of that little bit of time off.* Steve

All three quotes reflected the academic environment that students experience in engineering at this particular institution and suggest that institutions rarely recognize or address issues like communication gaps and the misalignment of students' expectations around learning methods and goals.

A second aspect has to do with the use and implementation of technology in courses. Two students noted how for some departments and students adding technological innovation can be difficult. On the one hand, a graduate student in Computer Science said,

> *I could say with other departments, the virtual environment implementation was not very good.* Thomas

This student realized that the use of technology was not easy to implement and that students can find it difficult to grasp. A second quote addressed students' issues in adjusting to a virtual environment, he added,

> *So I specifically think I did well in online curriculum, but I know a lot of students really struggle with it, staying engaged, participating, learning the material, there's a lot of problems.* Thomas

A second student, a senior in ECE and the only woman who was interviewed, reflected on the socialization aspect with studying and connecting with people, she mentioned,

> *Not everyone wants to do study groups, which is a little frustrating.* Yamileth

> *I think there's a huge under-representation (talking about women in engineering). So I think sometimes it's easier to make relationships with men, with boys, but still we are, I think as women we try to look for other women's support.* Yamileth

Technological and social aspects greatly influenced the academic performance and experiences of engineering students who strive to succeed in college.

6.2 Limited Sense of Community in Academic Settings

Our analysis suggests that currently hybrid learning at this HSI tend to make students feel less integrated into the academic community. In academic settings, community support is essential for tasks such as completing homework, conducting research, and working in ECE labs [42, 43]. However, students reported that they do not feel like a part of the student community in various academic contexts. A couple of students expressed,

> *I have not experienced very much community here. I have found camaraderie in the veterans group but nothing academically. At the moment I don't feel as part of a community as I did when I used to be an active member of IEEE, and back when <omitted for anonymity>had more people hanging out working on homework. I miss working with other people on engineering classes.* Steve

Some online classes can promote similar interactions by assigning discussions, but online learning is more often working alone. Juan

This suggests that ECE students are seeking greater collaboration with their peers in learning activities. However, while the hybrid learning environment has enabled students to continue their education from convenient locations, it has also presents challenges in building a strong student community in which students do not feel isolated.

6.3 Motivation and Emotional Support Needed

During the group session, a student discussed how the ECE student community is significantly focused on academic activities. An undergraduate student expressed,

The community is being on campus because they're just here for the class. Rick

One participant recalled an instance in which the presence of community support could help emotionally. A PD participant shared,

One guy doing homework and talking on voice channel on discord simultaneous was found very helpful and sometimes I just used to listen and not engage really much but just thought it was cool. it was outside the office hours lending his own time. Juan

These conversations with participants revealed that students are seeking emotional support in addition to academic support. A participant expressed appreciation for the camaraderie while acknowledging the limitations of the support provided,

I'm working there. But it's.. it's more like emotional support and cold, we're here working together on things. Like..[sighs]..you can't really help each other on that exam. Juan

They recognize that while constant collaboration on projects alone may not help them complete their academic tasks, it will certainly aid in bonding and staying motivated in their academic goals. Participants also shared how club and community activities also helped them on personal level outside of academic contexts. An international master's student expressed,

I feel like I belong to the international students community at <omitted for anonymity>due to the inclusive environment that embraces diversity, the support network of fellow international students who share similar experiences and challenges, the cultural events and activities that celebrate different backgrounds. Milo

Organizing these community-building activities can prove a challenge in an online environment whereas it would be trivial by comparison in physical spaces. In our discussions, participants noted that ECE students are also seeking better social interactions and inspiring activities within the academic environment. These community building activities appear to be lacking in online learning settings.

6.4 Search for Common Communication Spaces

In a PD session, one participant mentioned how it is easier to convey one-self when conversing in-person rather than online. A veteran engineering student expressed his concern,

> *In-person allows for non-verbal communication. In an online environment, great care must be taken to avoid misunderstandings without that additional information.* Steve

The participant further voiced their frustration about the inundation of communication media used in the academic setting and a fear of using unknown software that may take his work without permission. A PD participant vented,

> *Trying to communicate about something.. to share a picture was difficult but it was crazy because sometimes like.. I miss it because a lot of times it would just be like AirDrop say I was out we went to the bathroom while the air drops now I don't have that homework, I will be missing that homework.* Steve

> *I refuse to participate in anything if just blatantly steals everything I do.* Steve

This student later voiced a desire to reserve academic communication to a set of school sanctioned applications.

> *[...] something I guess maybe school sanctioned, this is [what] we are going to use will make it easier. it will take it off my duties [if] this is the thing that is [the] requirement.* Steve

These conversations indicated a lack of information and approval for systems that can be used to share homework materials, which need to be secure, easy to access, and standardized.

6.5 Need for Synchronous and Asynchronous Communication Systems

The ECE academic environment requires students to practice in laboratory activities with technical tools such as multimeters, breadboards, and oscilloscopes. In our PD sessions, some participants voiced a preference toward in-person labs rather than online. A few PD participants conveyed,

> *When it comes to hands-on activities like building circuits or working with tools and devices, I prefer in-person learning as it offers the advantage of immediate feedback, real-time interaction with instructors and peers, and the ability to physically engage with the materials, fostering a deeper understanding of the subject matter.* Milo

Participants reported having an increased level of focus and a decreased amount of distractions when engaging through in-person and learning as opposed to online learning. However, they also highlighted the advantages of asynchronous communication systems in online learning environments, such as the flexibility of self-paced learning and the ability to communicate expectations effectively. A PD participant expressed,

> *Online tends to have everything put out at once and you know what is expected of you. In-person can create a situation where a professor meant to put some information out and forgot to.* Steve

Online communication also offer flexibility for initiating conversations, especially for those who are hesitant to do so in-person. The asynchronous nature of online platforms has benefited students by enabling them to access class materials and share notes on a flexible schedule, regardless of their location or availability.

6.6 Design Preferences of MR Learning Spaces

Common spaces, such as libraries and lounges, as well as ECE laboratory locations play a crucial role in supporting student learning and socialization. During Session 2, students outlined how MR could enable a virtual space to mimic these crucial physical spaces (see figure 5). A master's student thoughtfully reflected,

> *This is what I can think of at the moment. A room filled with tables and chairs. And each of these kind of like gather.town if you go up to the table, you're in an area where other people can join you and talk and work on homework and share what you're doing and whiteboard area, which you might even have a whiteboard attached to each table as well, but just for the sake of being able to draw it somewhere.* Yamileth

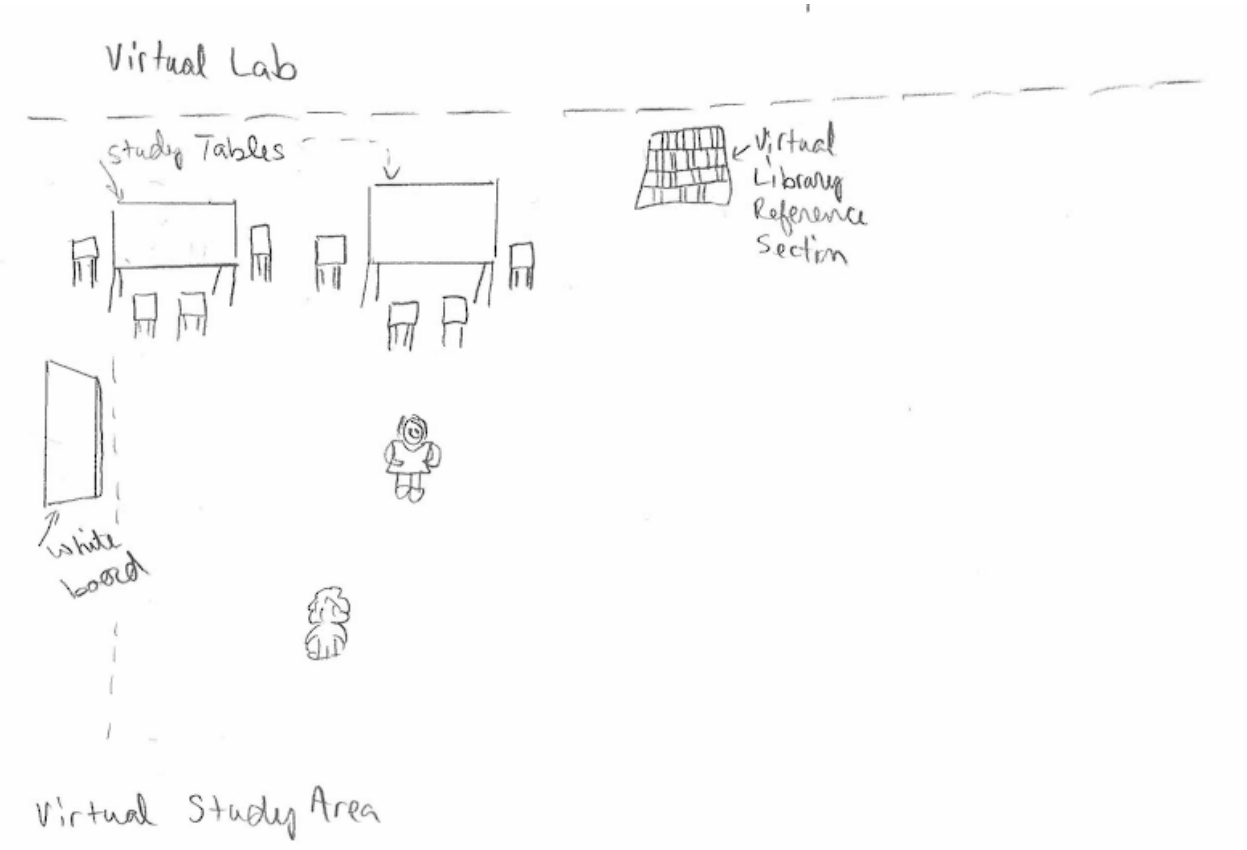

Figure 5: Low-fidelity prototype of a MR learning space designed by Yamileth during session 2.

The participant also suggested that the presence of a virtual library in such settings could be helpful.

> *I thought about this virtual library section where people can kind of check out a textbook or something if they don't have that textbook with them, but they don't have it like permanently is like stays there with the site.* Yamileth *MR/VR gathering space, in that we can have books corner, games corner etc.* Yamileth

While a virtual library could support students by providing essential reading materials, a crucial aspect of learning within the ECE context is working with equipment within laboratory activities. The inclusion of these aspects of learning is further demonstrated by another participant.

> *We have used transformers and motors, induction motors, different different motors, basic motors, so, maybe we can have a reality or AI version of these machines and scan them will be able to interact with these machines.* Milo

In our discussion with ECE students, we observed that, in addition to the need of improved interaction in educational environment, the infrastructure design and availability of ECE resources such as laboratory equipment and libraries in certain spaces also played a crucial role in shaping students' educational experiences. Thus, accounting for these types of resources in virtual ECE learning spaces will be critical.

6.7 Representing Presence of People in MR

Participants emphasized the need of appropriate representations of people in MR space. Two PD participants shared,

> *Real time interaction with virtual participants. Some sort of manifestation of virtual participants.* Juan

> *[online students] can't experience everyone who's sitting in the seats. So they're in a classroom with [...] two other remote people. [...] Maybe if there was a way to put physical people, track them and walk them around so that we walk into the room and your data's are pops up and you move around, maybe that's the way to go community that way.* Steve

We noted a preference for clear participation mechanisms in virtual presentations made by students and instructors in MR spaces. For example, participants also discussed the importance of making visible certain actions taken by students, such as voting on ideas presented by a speaker during a presentation.

> *Interaction with audiences, but if it's just the vote, then I think it'd be pretty easy to have some sort of digital manifestation of the vote in that area, instead of back to the screen.* Juan

It is clear that participants valued the visibility of their peers, whether attending classes online or in person. They proposed various methods for representing themselves in MR, such as using digital avatars and accurately depicting students attending in person with near-field communication (NFC) tags to reflect their locations in MR.

6.8 Types of Activities to be Supported in MR

In the PD sessions, laboratory activities were identified to be a crucial and challenging activity needing to be supported in MR space. These laboratory activities often consist of synchronous collaboration between a team of students. A PD participant expressed,

> *So if there is like two students in a team, so one of them is working on the software implementation of the of the circuit, and the student is working on the hardware implementation of the switch. And the kind of the task is to like build a circuit board the other and software and then take readings and compare if they're kind of comparable or not.* Milo

Participants further emphasize the importance of haptic and visual feedback when interacting with laboratory equipment in an MR space. An engineering master's student elaborated,

> *There's usually a knob to adjust like a tuning knob, and usually some places for cables to connect. And this is like the view screen and this oscilloscope so similar, usually has like a couple of different tuning knobs. It has an input [with] two inputs and a ground. I don't remember right, but basically, so it would be especially useful to be able to interact with these buttons for someone who's like trying to take a class virtually to kind of get in their mind like what kind of things you need to interact with when you're trying to use this equipment.* Yamileth

ECE students' learning environment need to support practicing in laboratory on workstations with various tools, and equipment. In the workshop sessions, some students suggested some social activities that can help in bringing students to common spaces, such mentorship programs, diversity and inclusion workshops, collaborative projects across disciplines, working on modeling kits collaboratively, informal study sessions with instructors, and programming competitions. Two PD participants stressed,

> *If we had some board games or something. Perhaps it would attract some students.* Milo

> *Maybe something to build together in teams? Like model kits?* Yamileth

After gathering data on students' preferences for community-building activities, the designer-researcher team presented a (MR) prototypes using Gather.town [41] as a MR space prototype medium. This space supported two types of activities: social and educational. The researcher team facilitated an ECE laboratory based activity where two students were present in-person and one student was present online. The ECE laboratory activity involved constructing a simple circuit on a physical and virtual breadboard synchronously. Gather.town provided a virtual whiteboard for online students and a camera to integrate physical whiteboard activities for in-person students, which facilitated a synchronous Pictionary game. The feedback obtained from synchronous interaction facilitated in the role play activities, were positive and emphasized how it matched their expectations in socializing. A PD participated expressed,

> *The shared whiteboard was great and just as I thought it would be!* Juan

The activities suggested by participants indicate that students are seeking for community support not only in classroom or coursework related activities but in other social activities as well. This indicates a need for meaningful technology that enables effective communication, critical thinking, problem solving, and collaborative team-work.

7 Discussion

The data collected from interviews and PD sessions highlighted challenges present in current methods of interacting, collaborating, self-representation, and socializing online for ECE students. In this section we reflect on the findings in terms of our initial research questions. Particularly, we focus on the existing learner community challenges faced by ECE students at this HSI. Finally, we begin to reflect on the second research question and critical issues to consider when designing future inclusive MR spaces.

7.1 Existing Learning Community Challenges

With respect to our first research question, we identified several existing learning community challenges at this HSI. Primarily this included that participants felt a distinct lack of sense of community, which participants reported led to a lack of motivation and emotional support. Several scholars have highlighted the important role that key figures (e.g., peers, faculty, and staff) have on students developing a feeling of belonging, engagement, and motivation [10, 13, 11, 12]. The nature of distance learning, which helps students to continue their education considering financial and family conditions, raised a lack of sense of connectedness and membership among students as framed by Strayhorn [7]. Indeed, in engineering, students rarely socialize and collaborate with each other outside courses. Such behaviors are usually emphasized by women who continue to be highly underrepresented in engineering [10, 12].

Our primary aim in our future MR technology and activity designs is to work towards addressing this overall lack of community. Further, students reported a distinct need for more designated community spaces, both digital and physical. We note this has recently been exacerbated by the demolition of prior ECE facilities, which included spaces for students socializing and collaborating on academic work. While likely not a total solution, we envision future MR spaces as being able to serve to some extent, particularly for remote students, in this role.

According to Strayhorn [7], feeling valued and connected within a group fosters security and in turn better student academic performance and increased social engagement. During one-on-one interviews, students expressed multiple challenges that they face daily as engineering students. For example, students reported that instructors often struggled to communicate effectively and make course content relevant to students. Such an issue may result in students feeling unseen and unappreciated in their academic program affecting an effective sense of belonging [7]. Additionally, students explained that instructors needed to improve to connect lectures with laboratory activities to better apply abstract knowledge to real-world problems. While we don't expect to solve issues such as these with technological interventions alone, we hope to make instructors and teaching assistants more accessible.

7.2 Synchronous MR Spaces for Learning Community Activities

While participants reported currently feeling a lack of community and needing additional collaborative spaces, both physical and virtual, participants particularly enjoyed the role-playing PD session. Students appreciated how MR prototype enabled them engage in collaborative laboratory work and engage in playful social activities such as playing games. The role-playing session with the MR prototype demonstrated participants' sense of connectedness and membership within a group, whether they were online or in-person. This experience fostered a sense of belonging by enhancing feelings of security and relatedness in the environment, as proposed by Strayhorn [7]. This aligns with prior work that finds that synchronous online modalities and activities in online learning supports community building and social learning [44, 45, 46, 47, 48, 49].

In response to the second research question, we envision that MR can be applied as a method of supporting synchronous community activities in both academic and social environments. Our findings suggest that synchronous modalities such as shared digital whiteboards and live video and audio streams bridging both physical and virtual environments would help improve remote learners' ability to interact in meaningful ways with their in-person peers. This approach would help fulfill the basic need for connectedness and membership within the learners' community, thereby enhancing their sense of belonging [7].

7.3 Supporting Social Presence in MR

Garrison and Anderson define social presence in online learning as the "ability of participants to identify with the community, communicate purposefully in a trusting environment, and develop inter-personal relationships with way of projecting their individual personalities" [50]. Building on the foundational needs identified by Garrison and Anderson, we focus on the specific social presence dynamics within ECE learning. During the PD sessions, students expressed a clear need for social presence including tools for self-representation, synchronous interaction, and virtual access to ECE digital tools and medias. In PD session 2, all the students suggested incorporating avatars or physical representations of online students into the virtual classroom, and vice versa, to reflect their presence and movement accurately. Juan emphasized that getting to know someone before interacting can help in icebreaking. He suggested using AR tags to identify students, addressing the need to be seen as a requirement of the sense of belonging [7].

We also recognized the need of fostering social presence by creating a space where students feel seen, heard, and valued by their peers and instructors. This could be achieved by creating a shared platform where students can exchange experiences, collaborate, and engage in activities across both physical and virtual spaces. Such a platform would support their self-representation and reinforce the need for authentic acceptance, which again is significant for fostering a sense of belonging [7]. Collaborative presence would also involve simultaneous interactions using learning tools, e.g., digital libraries and laboratory equipment, especially when performing interdependent tasks such as those in ECE laboratory work. Our findings suggest that a virtual environment incorporating these features, may significantly enhance the online learning experience.

8 Future Work

Our future plans include designing and developing a more sophisticated MR platform to address the issues identified within this paper. The first concern we aim to address is enabling students to socially interact with each other in both in-person and remote settings to participate in shared learning and social activities. The researcher team envisions that this MR platform will incorporate two environments, a physical space in the form of a classroom augmented with equipment and a virtual space in which students may control avatars and interact with one-another. These two spaces will be linked to each other through the digital devices in the physical space.

MR equipment we plan to incorporate and study includes telepresence robots, smart-whiteboards, and laboratory equipment that is linked with synchronized digital twins. We envision the telepresence robots serving as physical avatars for students who need to interact remotely through the virtual environment. Our goal aims to provide these individuals a heightened sense of presence and agency when interacting with peers in the physical environment. Smart-whiteboards will serve as a shared canvas between the in-person and virtual environments allowing students to collaboratively communicate ideas. The laboratory equipment and digital twin will enable students to engage in coursework activities to be performed synchronously by teams of students which may have both in-person and remote members.

We expect these approaches will begin to address some of the existing issues with learning community identified in this paper. We will continue to engage in an iterative participatory design approach that will enable students to continue to play a central role in design and deployment of inclusive learning community spaces.

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