Navigating the Cyborg Classroom: Telepresence Robots, Accessibility Challenges, and Inclusivity in the Classroom

HOUDA ELMIMOUNI, Indiana University, USA
SELMA ŠABANOVIĆ, Indiana University, USA
JENNIFER RODE, University College London, UK

Telepresence robots, designed to bridge physical distances, have unique capabilities and inherent limitations when deployed in classroom environments. This study examines these aspects, focusing on how telepresence robots facilitate or hinder classroom accessibility and inclusivity. Based on field study results from participatory observations, surveys and interviews with 22 participants, we present and catalogue the operational capabilities of telepresence robots, such as mobility and interaction potential, alongside their limitations in areas like sensory perception and social presence. Our findings reveal a nuanced landscape where telepresence robots act as both enablers and barriers in the classroom. This duality raises the question of whether these robots can be considered "disabled" in certain contexts and how this perceived disability impacts remote students' inclusion in classroom dynamics. Finally, we present use recommendations to improve classroom experience and telepresence design.

CCS Concepts: • **Computer systems organization → Robotics**; • **Human-centered computing → Empirical studies in collaborative and social computing**; **Collaborative and social computing design and evaluation methods**.

Additional Key Words and Phrases: Robotic telepresence, robot-mediated communication, remote participation, classroom, accessibility, disability, inclusivity, cyborg

ACM Reference Format:
Houda Elmimouni, Selma Šabanović, and Jennifer Rode. 2023. Navigating the Cyborg Classroom: Telepresence Robots, Accessibility Challenges, and Inclusivity in the Classroom. In ,. ACM, New York, NY, USA, 20 pages. https://doi.org/...

1 INTRODUCTION

Robotic telepresence promises to make classrooms accessible for students who are not able to attend in-person due to diverse reasons: illnesses, injuries, physical disabilities, autoimmune conditions, and COVID infections. It does better than traditional telepresence media— such as online courses and video conferencing— in emulating a face-to-face setting [Fitter et al. 2020b; Rae et al. 2013]. Many embodied social cues are available when telepresence robots are involved, such as facial expression, intonation and physical movement in space. This offers students the possibility of moving around in the classroom and interacting with their classmates and instructor in physically situated ways.

Many studies have explored the support of robotic telepresence for office work [Björnfot et al. 2018; Rae et al. 2012; Takayama and Go 2012; Venolia et al. 2010], attending conferences [Erickson et al. 2011; Neustaedter et al. 2016], hospitals [O'neill et al. 2001], home [Boudouraki et al. 2022; Neustaedter and Yang 2017; Yang and Neustaedter 2018; Yang et al. 2017] and education [Fitter et al. 2018; Lei et al. 2019, 2022; Newhart and Olson 2017; Weibel et al. 2020, 2023; Williams et al.

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1997]. The focus of such studies has been on the usability and user experience, adoption, quality of interaction, embodiment, and interaction aspects and often contributed design recommendations. There is further need for research at the intersection of robotics and disability in SIG ACCESS venues. While there are studies on assistive robots, such as Bonani et al. [2018], we could only identify one poster paper on robotic telepresence intended to improve the self-efficacy of people with developmental disabilities, as presented by [Friedman and Cabral 2018].

One aspect of this work that is novel, in SIG ACCESS venues, is that we focus our study on the classroom. Also, the ways in which telepresence robot designs affect many of the salient user values — such as identity, privacy, and courtesy— reflect those of a corporate profit-driven context where information is considered the property of the company not the individual. While we see many critiques that education is increasingly primarily motivated by profit[del Cerro Santamaría 2019], education in its purest form has goals of human development which bring with it different values centered on individual growth, requiring articulation work for students and teachers to bridge this socio-technical gap [Ackerman 2000]. Classrooms also have different power dynamics than offices, where students defer to instructors with less in the way of clear rights than those in employment. This power dynamic is further exacerbated by the dynamics of age, and inexperience. Thus, classrooms are in and of themselves a novel context worthy of independent consideration.

An interesting perspective arises when we consider the inherent limitations of these robots in the context of disability. Drawing upon William's insightful work [Williams 2023], we explore the notion that telepresence robots, in certain scenarios, can be conceptualized as "disabled." This perspective stems from the idea that the constraints and limitations experienced by these robots mirror the challenges faced by individuals with disabilities. We will argue in this paper, many of the strategies needed to mitigate the disabling aspects of telepresence in the classroom, will simultaneously improve accessibility for disabled students not using telepresence. Such a viewpoint not only enriches our understanding of the human-robot interaction in educational settings but also invites us to reconsider the design and deployment of these robots. By acknowledging the 'disabilities' of telepresence robots, we can better appreciate the nuanced ways in which they contribute to, or detract from, the educational experience.

While prior work labeled similar limitations as functionality issues [Weibel et al. 2020] or missing abilities [Fitter et al. 2020a], framing it in a disability studies context in terms of accessibility brings fresh perspectives to the debate.

Thus, in this paper, we examine telepresence's accessibility to make the classroom more inclusive. While our study is based on the experiences of novice users, capturing these early interactions is crucial for identifying immediate barriers and challenges that new users face. Understanding these initial experiences can inform the design of more intuitive and user-friendly interfaces and features, ultimately benefiting both novice and expert users. This is especially important as bad onboarding experience can lead people to permanently quit using telepresence at which point they might be unwilling to give them a second chance. Additionally, continued use of technologies with features that do not support accessibility can lead to the development and normalization of practices that are not inclusive. Thus, our goal is to identify and catalogue accessibility challenges for students, and make recommendations for instructors and educational institutions on how to address them. We also provide design recommendations for telepresence robot manufacturers to ensure accessibility for all students, both disabled and newly disabled in the context of robot mediated communication. In our analysis, we followed a bottom-up approach to analyze screen recordings, notes, photos and interview transcripts with 22 participants. We inductively identified challenges related to the accessibility of the classroom to discuss to what extent telepresence robot makes the classroom accessible and inclusive. In addition to practical design and use recommendations, we contribute to the ongoing theoretical discussion of how to frame the limitations of humans using technologically mediated communications such as telepresence, and using Williams [2023] we discuss how to handle this potential "disability".

2 RELATED WORK

In this section, we review the literature on robotic telepresence and its relation to disability and inclusion, particularly in the context of education. We will start generally with the literature on robotic telepresence, and then move on to discuss the importance of telepresence in the education of disabled students. In order to contextualize this we will introduce [Williams 2023]'s argument that all robots are disabled, in that robots typically have limitations an person with disabilities would not have, for instance difficulty seeing, hearing or moving through space. We connect this in the literature on making telepresence accessible for disabled students in the classroom.

2.1 Robotic Telepresence

Various forms of mobile robotic telepresence (e.g. Beam, Double, GoBe) each have their own accessibility strengths and weaknesses. They typically consist of video conferencing systems in addition to being physically embodied, granting remote users — the *operators* — the ability to move in and navigate a remote space [Jackson et al. 2019]. The COVID-19 pandemic increased the perceived importance of remote participation [Russell et al. 2021] and robotic telepresence [Brock et al. 2021]. Unlike video conferencing applications (e.g. Zoom), robotic telepresence is especially useful in contexts where the participant is the only person participating remotely, as it helps to mimic face-to-face interactions between the operator and interlocutor [Rae et al. 2013] (e.g. facial expressions, human-sized embodiment, and mobile control), and act as the physical embodiment of the operator in order to maintain social interactions with peers [Fitter et al. 2020b], but the technology is not without flaws which we hope to investigate.

Work related to robotic telepresence in educational contexts revealed that the use of robotic telepresence provides numerous benefits to remote students who cannot attend class in person, especially in comparison to videoconferencing [Fels et al. 2001; Newhart et al. 2016]. Studies overall focused on students' experience [Fitter et al. 2018; Lei et al. 2022; Liao and Lu 2018a; Schouten et al. 2022], acceptance and adoption [Lei et al. 2022; Newhart and Olson 2017], interaction [Fitter et al. 2018; Schouten et al. 2022] and engagement [Fels et al. 2001; Lei et al. 2019]. Similar issues to what we present in our findings are mentioned in some of the above studies but are often framed as UX, usability or as purely technical problems to be solved. For instance, Ahumada-Newhart and Olson [2019] pointed out how restricted camera views and lack of panning restrict visual exploration without moving the robot, alongside sound issues like echoing and volume control challenges that impair communication. Liao and Lu [2018a] also reported on volume problems, with participants needing to speak louder, and noted the robots' slow speed, which sometimes required peers to physically move the robots. We argue that there is a need for studies that frame the issue in terms of accessibility as this frame allows for new insights in meeting classroom needs. We contribute to this gap by identifying and cataloguing the accessibility limitations of the telepresence robots and discussing the disability in a telepresence context.

2.2 Theories of Robotic Telepresence and Disability

Svyantek and Williams [2022] discussed how organizations which limited disabled staff and students' access to telecommuting prior to the COVID-19 pandemic rapidly moved to accommodate telework during it. They raise concerns that in an effort to "return to normal" and shift back to collocated workspaces, the medical needs of the disabled including the immunocompromised and those with long COVID, are again being forgotten. Telepresence allows a novel solution to the problem, in that able bodied workers can return to face to face work, as they inevitably will, given the social tendency to prioritize needs of people without disabilities over the disabled. Telepresence affords disabled workers more embodied access to these spaces than previously afforded by Zoom calls. Thus, in an increasingly post-pandemic world, telepresence has novel affordances for inclusion.

Scholars have long discussed the disabled as the original cyborgs with artificial limbs, hearing aids, and sight augmentation devices [Shapiro 2015]. Yet, telepresence robots present a new form of cyborg, as they allow an augmented whole body experience.

Williams [2023], Rebola and Eden [2017], and Rode [2018] have all highlighted the connection between cyborgs —human-robot hybrids— and disability. Williams, asserts *"All robots are disabled,"* referring to the deficit lens used to discuss disabled people [1] using robotic limbs as a sort of everyday cyborg. While Williams [2023] do not explicitly focus on telepresence robots, Rebola and Eden [2017] make a similar broad point about telepresence robots specifically. A key difference, however, is that Williams [2023]'a sensitive framing using disability theory is omitted from earlier discussion. Williams discusses what it would mean to consider alliances, and makes provocative suggestions as to how disabled robots and disabled people could solve common problems for cyborgs that have both new abilities and disabilities. In this paper, we pick up on Williams theory around cyborg articulation work to understand what it entails, and the extent to which the cyborgs using telepresence robots are disabled.

Articulation work is defined in the CSCW literature [Gerson and Star 1986; Schmidt and Bannon 1992; Strauss 1988] as the work that aids the coordination of cooperative work. In a telepresence context this means monitoring the volume level, battery level, WiFi signal, your location, managing the zoom level on your input camera, ensuring you are visible on your output camera, and maintaining appropriate interpersonal distance. There is a lot of work to presenting oneself using robot mediated communication, and even if one does all this articulation work masterfully the lived experience of using a robot can feel disabling. Thus, we are using Williams theory to understand how to address the shared difficulties of disabled and non-disabled robot users.

Rode [2018] in her autoethnography discusses her experiences as a disabled person using a telepresence robot including articulation work, she explains *"The telepresence robot did not 'fix me'... or augment my experience to make it more palatable to the able-bodied majority. Instead, it allowed me to make conscious trade-offs between the affordances of my corporeal body and an emergent cyborg-self in the context of a degenerative autoimmune disease."* (p239). In doing so she rejects the medical model of disability, and uses and social model of disability to frame her work. Rode in her work highlights that the cyborg is neither a fix nor a deficit but a unique assemblage of abilities. She highlights how in some ways it compensated for her disability giving her increased robotic stamina, akin to her prior able-bodied self, and a way to avoid travel that her disability made difficult. In some ways it gave her enhanced abilities like the ability to zoom-in and have better vision than her human self or *"handless feeling"* even when participating remotely. Finally, it had some drawbacks and created articulation work in that she discovered her participation was limited by battery life, WiFi signal, stairs, and difficulties moving her robotic self [Rode 2018]. Rode then advocates conscious manipulation of abilities and limitations and embraces her cyborg self-mediated through a telepresence robot. In this paper, we wish to broaden that understanding from one autoethnography to a classroom of students' experiences with their newfound cyborg selves.

Williams [2023] and Rode [2018] both explore articulation work around human-mediated robot interactions. Whereas, Rode [2018] focuses on the disabled person's experience as a mixture of

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[1] Note as ACM SIGACCESS recommends following the UN Disability Inclusive Language Guidelines, we are following their conventions. We recognize though that person first language is considered offensive to individuals in some countries who prefer being called a 'disabled person' in that that is nothing to be ashamed of. We apologize to those readers, and beg them to understand we are following the majority norms.

both power and limitation, Williams focuses on others' perceptions of the robot and argues that only the deficits are recognized. These theories can live alongside each other comfortably in the present moment, though, one wonders if in time the telepresence robot might be recognized by others as both a liability and a strength. Regardless, in this paper, we will explore this tension.

2.3 Studies of Disabled Users of Robotic Telepresence

Zhang and Hansen [2022]'s systematic literature review shows 42 articles published between 2009 and 2019 on teleperesence and "special needs". These "special needs" range from 26 papers on motor disabilities, 4 on visual disabilities, 3 on cognitive disabilities. This research shows a gap in discussions of telepresence amongst people with neurodivergences and mental health conditions. This is despite many impacted parties with both conditions having difficulty leaving home. In the case of Autism, for instance, public transport can lead to sensory overload. Of the papers 11 focused on a targeted age group, including 6 on "homebound" & hospitalized children and 5 older adults, with the balance of papers discussing a range of ages. This suggests that young adults, such as college students, are an understudied demographic. While the research on children focused on education, the majority of the adult research focused on socialization, making adult education a gap in the literature. This suggests that research on disabled adults in higher education is under studied.

Elsewhere in the literature we see research on college students using telepresence robots. For instance Khojasteh et al. [2019] poster paper presented study of undergraduates who had trouble approaching others to communicate due to concerns with self presentation, coping with the novelty of the robot communication, and interpreting non-verbal cues. This work, however, did not discuss disabled students nor engage in a disability studies frame. The same holds for research by Dimitoglou [2019]. Research by Patel et al. [2022] has investigated telepresence for teaching students surgical skills. Liao and Lu [2018b] investigated a language learning context. Thus, this suggest while there are domain specific studies and some overall usability studies, the disability studies lens of this paper is unique.

3 METHOD

In order to understand the accessibility that telepresence can provide through the experience of the students, we conducted an empirical qualitative bottom-up field study. We observed students' participation and documented ensuing interactions. We collected behavioral and attitudinal data about the experience of remote students who attended one class session remotely via the Beam telepresence robot, which is the smaller more nimble robot of the two offerings by Suitable Technologies.

The study involved participant observations, surveys, and interviews and was collected in Fall 2022. This study was approved by the IRB at Anonymous University where data collection occurred.

3.1 Setting

In our field study, students traveled around the building to the classroom. We placed the robots' charging docks in our lab, however the students immediately drove the robots out of that space. Thus, we would position this as a naturalist and not a lab study, as labs are part of the campus environment of an Informatics department, and this facilitated easy access and coordination. The students operated the Beams from designated areas within the same open lab space, rather than separate rooms. Each student was provided a desk equipped with a computer that had the Beam software installed, allowing them to control the robots. We conducted the study in two informatics classes, Health Informatics and Human-Robot Interaction. The classes met twice a week for 80 minutes and included a mixture of lectures, discussions, group activities and presentations. An assistant was assigned to accompany the student using the Beam, offering necessary physical support during the study. For instance, when encountering a half flight of stairs, a research assistant was required to physically transport the robot up and down. Meanwhile, a second assistant was stationed in the lab alongside the remote student controlling the Beam. This assistant's role was to offer technical support with the Beam interface as needed, such as addressing issues like internet connectivity loss, or audio and video technical problems.

3.2 Participants

A total of 22 students attended classes via telepresence robots (F=11, M=11, NB=0), aged between 19-31. We had a mixture of undergraduate and graduate students majoring in data science, computer science, engineering, and human-computer interaction. Of these, ten students were enrolled in a health informatics class, while twelve others were attending a Human-Robot Interaction course. About 25% from each class participated in the study. We did not recruit based on disability status, as we wanted to get a representative cross section of mixed ability students. At this time, given the lack of data on best practices for teaching with telepresence in the classroom for students with or without disability, despite our interest in using telepresence to support disabled students, we did not feel it was ethical to start research with exclusively disabled participants. We felt it was more appropriate to start in a mixed ability classroom, but frame our discussion of results in a disability studies context. We do not have access to our students disability status. However, as our university has an 11% disabled student body [citation redacted], we anticipate our classroom has a typical mixture of students with mental health conditions, neurodivergences and invisible disabilities. While our sample was not focused on disabled students, our future work will investigate disability specific access needs. None the less, despite the majority of our participants typically not having access needs, we found once they were using telepresence they suddenly had them.

Additionally, our recruitment approach helped avoid conflating the effects of disability with those of telepresence technology. While this means our findings may not fully capture the unique experiences of students with disabilities, it prevents misinterpretation of findings and inaccurate design recommendations. Challenges specific to disabilities might otherwise be wrongly attributed to telepresence technology, leading to inadequate solutions. Thus, our results should be interpreted with this context in mind. While we provide valuable insights into the general use of telepresence technology, the specific accessibility needs of disabled students will require further targeted research.

Thus, we report our findings and our implications for design here at TACCESS in the spirit of allyship as discussed by Williams [Williams 2023]. Many of our design recommendations for accessible telepresence, mirror general best practice for teaching disabled students. Thus, we present our findings here to both SIGACCESS community as well as a broader audience encompassing educators, technology developers, disability advocates, policymakers, and caregivers. This inclusive approach seeks to create a synergy between accessibility research and its practical implementation in educational contexts, aiming to develop learning environments that are inclusive and beneficial for all students.

It is important to note that our findings are based on the initial experiences of novice users. Each participant used the telepresence robots only once, providing a snapshot of the early challenges and barriers faced by new users. This approach was chosen to identify immediate accessibility issues and inform the design of more intuitive and user-friendly telepresence systems. We chose to focus on the critical period of initial use, as if onboarding went badly students might not be willing to try this technology a second time.

Participants were offered 2 extra credits, which are additional points provided by the course instructor added to the total average of the student's grade, as a token of appreciation for their time. This practice aligns with the social norms at <anonymous university> and is deemed ethically appropriate by our Institutional Review Board (IRB), in accordance with local values. To recruit the participants, one researcher visited the class accompanied by a Beam robot and advertised the study. The instructor also posted on Canvas (a learning management system) more details about the study, including the contact information for the researcher so as to schedule their participation. The nature of this style of intervention is that students who used the robots at the start of class, had little experience with telepresence robots, whereas those who used them later in the term had prior experience with their classmates using them. All the students who volunteered for the study were able to participate.

3.3 Apparatus

We utilized three Beam telepresence robots supplied by Blue Ocean Robotics. While a maximum of two Beams were actively used at any given time during the study, the third was available as a contingency measure in case one of the operational Beams encountered technical issues. The Beam robot merges an upright, mobile design with a screen for interactive communication and a wheeled base for easy navigation. It is remotely operated and outfitted with both top and floor cameras, along with an audio system, enabling efficient two-way communication. Control is facilitated through the Beam app. The robot's battery typically lasts for two-hour and can be easily parked to charge on the docking station. The Beam pro is smaller and slower than the unit studied at CHI by Neustaedter et al. [2016], which might be more recognized among conference attendees. (See figure 1 for a detailed description.)

Fig. 1. Diagram with sizes of Beam system and docking station. Photo credit: Blue Ocean Robotics

We provided two personal computers for student use, each equipped with headphones. This was to prevent audio feedback when multiple students used the lab simultaneously. These PCs were installed with all the necessary software, including the latest version of the Beam application, to ensure smooth operation. For the purpose of recording the Beam's screen during sessions, students were instructed to initiate a Zoom call, share the Beam's screen within the meeting, and record the proceedings.

3.4 Procedure

Since none of our participants had experience operating a Beam, all participants were asked to come thirty minutes before class starts to be trained about how to safely operate the Beam. Participants were instructed to participate as if they were attending in person and situate themselves in the classroom as they felt appropriate. The instructors and classmates were not given any specific directions or instruction on how to deal with or treat the remote attendees. By refraining from giving explicit instructions, our aim was to capture genuine reactions and spontaneous strategies that might emerge in a real-world educational context. Additionally, we were aware that classroom materials were readily accessible on Canvas, so we did not make further requests for accommodations from the instructors, ensuring a standard learning environment for all participants.

The assistants took photos and notes whenever an intriguing event occurred.

After the class concluded, the Beam operators navigated the Beam out of the classroom and returned it to the docking station. Each participant attended only one class session via the Beam. Upon their remote classroom participation, the participants were requested to complete a short after use survey and schedule an online or in-person interview within a week. The interviewer reviewed the recordings to supplement the interview questions. The interviews were audio recorded then transcribed.

3.5 Protocols

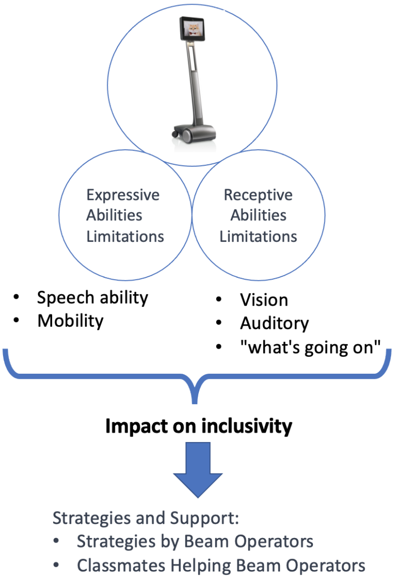
The observation protocol was open-ended. The assistant in the classroom and the lab were instructed to document with notes, photos and videos, what they found interesting, surprising, or unusual in the classroom and triggered by the presence of the telepresence robot. The after-use survey was a 2 min structured protocol hosted on Qualtrics. It has a total of 6 questions, 3 close ended questions and 3 open-ended questions. Its aim was to collect data about the users' demographics and overall experience. The scheduled interview was semi-structured with open-ended questions. The questions were informed by the recordings, photos, and observation notes. This allowed us to get in-depth information about the telepresence robot's operator' experiences, impressions, attitudes, challenges, and feelings about how accessibility impacted their participation. The interviews were used to gather deeper information from the point of view of the Beam operator, including the extent to which they felt participating in class was accessible.

3.6 Data Analysis

We used Thematic Analysis, [Braun and Clarke 2006] coding for themes and collapsing them into categories for analysis and applied Williams [2023]'s theory to help us make sense of our themes. While thematic coding can bear similarities to the open and axial coding of Grounded Theory [Strauss and Corbin 1997], we did not engage in the selective coding in light of theory which is required for this approach, rather we simply used theory to provide insight on our themes.

Our bottom-up approach commenced with weekly group meetings, involving five researchers, four of whom were research assistants and one is the first author of this paper. Together, we diligently followed the five stages of the thematic analysis process as outlined by Braun and Clarke [Braun and Clarke 2006]. First, we met to gain familiarity with the data corpus. Second, we inductively analyzed insights from 6 interview transcripts looking for initial codes [Braun and Clarke 2006]. The insights were written on post-it notes allowing us to begin the third phase of our analysis, searching for themes, where we organized into different themes on a whiteboard. Key themes we identified included difficulties in attracting classmates' attention, challenges in hearing, and issues with maneuvering the robot. The insights helped us create an initial list of codes. At this point we expanded our analysis to our full data set. Next, reviewed our themes. We identified more recurrent themes, collapsed themes

Fig. 2. Themes



and eliminated others while engaging in line-by-line re-analysis of the full data set. At this point we arrived at two major themes–around the receptive and expressive abilities using telepresence robots, and impact on the inclusivity of the remote student. In Braun and Clarke [2006]'s terms we ensured our themes formed a "coherent pattern" (p91). During this stage we arrived at our final thematic map focusing on expressive and receptive limitations and there sub-themes. Fifth, as per Braun and Clarke's we took our final themes and defined their "scope and content" to ensure each of the themes were clearly defined.

We report our more general findings from this study regarding issues, of privacy, courtesy and identity separately. Here we discuss findings with relevance to accessibility, and as such our thematic map only refers to that aspect of the data set, which we will present and discuss next.

3.7 Positionality Statement

Our team comprises three authors with diverse abilities and experiences. The first and second authors do not identify as disabled. However, the first author has acquired significant experience through nearly a decade of collaboration in the third author's lab, which includes many individuals with disabilities. The third author has a range of disabilities, including physical challenges due to lupus and cancer, vision issues from migraines, neurodivergence (such as ADD and dyslexia), and depression. Collectively, we believe our team possesses the necessary lived experience to approach the topic of telepresence with sensitivity to its implications for those with disabilities.

3.8 Ethical Considerations

To ensure our study on the use of telepresence robots did not adversely affect student participation or academic achievement, we implemented several measures to mitigate such risks: - **Limited Participation:** Each student's participation in the study was restricted to attending just one class session using the Beam robot. This approach minimized any potential prolonged impact on their overall classroom engagement and academic performance.

- **Accessible Materials:** We ensured that all necessary classroom materials were readily available on Canvas. This step was crucial to guarantee that remote students had the same access to educational resources as their in-person counterparts, supporting their academic needs effectively.

- **Support from Research Assistants:** Research assistants were present both in the classroom and the lab to provide immediate assistance whenever needed. This presence was critical in addressing any technical issues or challenges the students might face while using the Beam, thereby reducing the likelihood of any significant disruption to their learning experience. Finally, students had the right to withdraw and stop using the robot at any time. They could log off, walk down the hall, and rejoin the class in person, and would still receive the two extra credit points for participating in the study. We note none of our students elected to do this.

4 FINDINGS

Many robotic telepresence studies report on telepresence strengths and opportunities for its users [Ahumada-Newhart and Olson 2019; Neustaedter et al. 2016; Newhart 2014; Rode 2018], including disabled people [Rode 2018]. Similarly, our data shows numerous strengths of telepresence. Students mentioned they would be able to participate remotely on days they might not have felt well enough to come into the classroom and interact with their classmates. The robot's speakers allowed the user to easily project their voice across the classroom. And while sometimes they were perhaps too loud, the flip side is that they could easily be heard. Studies also revealed that remote students using telepresence robots faced limitations [Ahumada-Newhart and Olson 2019; Liao and Lu 2018a] that we present here as accessibility limitations. In particular, our participants reported not being able to see or hear clearly and be fully aware of "what is going on" around them. They also reported being too loud or needing to repeat themselves, not being able to move freely in the classroom, rotate the robot display or adjust its height, climb stairs and move as fast as others. Drawing inspiration from the categorization of abilities in the field of linguistics Kwok et al. [2015]; Peter [2012], we organize the limitations into two primary categories: those affecting receptive abilities and those impacting expressive abilities. Next, we provide illustrative quotes to explore the impact of telepresence robot accessibility on classroom inclusivity. Additionally, we engage in a discussion around the question of whether telepresence robots can be regarded as "disabled."

4.1 Receptive Abilities Limitations

Receptive abilities concern receiving information from the classroom environment through senses. Remote attendees had limits to their visual and auditory capabilities, and a situational awareness limitation. Our participants reported limitations in regards to the above stated capabilities which we detail and illustrate from the data.

Vision limitations: Vision limitations are the most common among our participants. 19 participants highlighted they could not see the slides, the whiteboard, or artifacts from classroom activities. For example, despite being in the first row and zooming, P12 was not able to see text on the slides: *"some of the text or annotation text and the pictures were not clear, even after zooming. I was in the front row."* Similarly P16 could see the pictures but not the small text. He mentioned he *"could not read anything."* As for P18, the issue was the color contrast on the slide. He said: *"So that was actually a big issue for me... the presenter was using images... there's blue lines and there were different colors... I even tried using the zoom feature, and it was too blurry... I felt like I was missing out on some contents."* While P18, P29, P12 and P19 mentioned zooming to see the slides, P3 mentioned zooming to see what the instructor wrote on the whiteboard but that did not help. Also, P3 mentioned he was working with a teammate on an activity where his teammate needed to write a note on a piece of paper. For P3 to see the note, his teammates held it up to face the camera but P3 found it: *"really difficult to read."* The fact that students were not able to see the small text or low contrast may be due to the size of the text and the quality of photos that the human eye can capture better that the Beam camera. The restricted camera view and the absence of pan capabilities, was also identified by Ahumada-Newhart and Olson [2019] as limiting students' ability to visually explore the classroom environment without necessitating the movement of the entire robot.

Auditory limitations: 11 participants reported issues with hearing others. P13 mentioned she could not hear the instructor because of the audio quality, consequently during the Q&A she had no questions. She said: *"I could not hear the instructor clearly. So I don't know what question I want to ask."* The inability to ask questions here could impact her overall understanding of the lecture. P16 was not able to hear his classmates even though they were right in front of him. He mentioned that he was talking to one of his classmates who decided to leave and said goodbye and left. Since P16 did not hear him he was wondering why he suddenly left. He says: *"he said bye guys. And then when he looked back, he realized that I was still here."* People talking behind the Beam are, in particular, difficult to hear. For instance, while P7 could hear the instructor well when she sat in the second row, she was not able hear people in the back during the Q&A: *"I had a hard time hearing anybody that wasn't directly in front of the robot... I was at the second row. And in the Q&A, we have students asking questions all around and behind. And I was having a really hard time being able to hear them."* P2 confirms: *"If anyone speak[s] behind the robot, we can barely hear."* The Q&A part of the course poses challenges for the remote attendees regardless of where they position their robot, as remote attendees in the front of the room can hardly hear questions from the back, and vice versa. In Ahumada-Newhart and Olson [2019] study there were sound challenges that concern echoing or difficulty in adjusting to the appropriate level for the classroom environment, which potentially hindered communication and engagement.

Situational Awareness limitations: 13 students reported not having the same sense of what was going on around them, that they would when they are in the classroom in-person. P9 compares being in the classroom in-person and using the Beam: *"I'd say you just have a better perception of everything when you're a person where there comes like what you see what you hear if you can make sense people behind or in front of you. But I guess with the Beam you're only really limited to what you can see in front of you depending on which direction your turn and then also what you can hear in general vicinity."* Similarly, P22 thought she can be aware of only what is in the front of the Beam. She mentioned things that could happen while she was not aware of them: *"maybe I was stuck, like, in the middle of the routes and like, somebody's waiting for me, but I don't know."* The fact that the Beam operators *"cannot notice everything around [them]"* as P16 put it could have been related to either limited field of vision or peripheral vision. Another reason could be not being able to tell where the voice is coming from and how close it is to the Beam's body. When co-located our hearing can detect spacial location of the sound, listening through the Beam does not help make such inferences.

In summary, participants reported limitations related to seeing, hearing and sensing the events occurring around them. Such limitations may impact the remote students' understanding but also their interactions with their classmates as well as the classroom dynamics.

4.2 Expressive Abilities Limitations

The expressive abilities involve all kind of movements enacted by a person to express themselves. For the telepresence robot these are limited to speaking and moving around in the remote space.

Speech ability limitations: Some remote students struggled with being heard as either their audio was too loud or too quiet, they talked while their microphone was muted, or did not feel comfortable verbally attracting attention if the teacher failed to see they raised their hand to talk.

13 participants mentioned that they found it difficult to determine whether their audio volume was appropriate. P3 mentioned that he *"never figured out what's better, and how [he] could... make them hear [him] better."* Similar findings about the volume was reported by Liao and Lu [2018a] as some of the participants mentioned they had to talk louder so others could hear them.

Some participants mentioned that they recalled hearing the telepresence robot's volume when it was used by other students in their classroom and that it was louder than they expected, but others took note that they could not remember or gauge how it was that the robot sounded on their behalf. Some of the participants mentioned adjusting their volume to find an ideal level and avoid disruption. This includes P1, who expressed that *"people are leaned in because they can't hear it. But when I turned it up, people were like, wow, that's really loud."* P2 tied knowing how loud the volume was to *"confidence"* he said *"there is no proper confidence while you're speaking because we don't know how the audio works... If we have confidence that the audio is good, we can speak properly."* This point is very important, as it suggests lack of confidence that volume was of an appropriate level discouraged a student from further interacting with their classmates.

The fact that raised hands on the screen of the Beam were not noticed represents another limitation to speech expression. P18 explains: *"my hand just every time I raised it, the lecturer didn't see it. And I don't think that was his fault. Like I was trying to make eye contact through the screen. And you can't make eye contact."* P18 made many attempts to raise his hand to talk but ended up un-muting himself towards the end of the class to talk, but he was afraid to interrupt consequently he did not ask any question. All of this suggests students struggled to express themselves verbally through the Beam, and while this could improve with practice the technology itself could be redesigned to support such interactions.

Mobility limitations: Several students (7) complained about the physical movement challenges such as getting stuck, not being able to rotate the Beam display alone or adjust its height, climb stairs and move faster.

Some participants expressed they could not move the Beam because they became "stuck", whereas for others fear of being stuck left them afraid to move. P12 described how the stem of the Beam snagged a chair even though the navigation camera looked all clear. Some of the students who got stuck were afraid of moving lest they get stuck again, e.g. P4 who described her hesitancy to move due to obstacles: *"I, honestly was not in a great spot... and I was like, Well, I gotta be in the front row, because I can't really see but I want to be behind the desk, just because I'm a student ... But I also didn't want to have to go ... I see all these chairs and obstacles galore."* If the way to what P4 thinks is the best position was clear, her receptive abilities would have improved as she will be able to see and hear the lecture better.

Students wanted to be able to rotate just the upper most display or to adjust the height of the Beam — which they called the "head" of the Beam— to face the speakers without moving the whole Beam's body. E.g. P1 said: *"it was kind of annoying having to turn the entire robot and I just want to turn my head..."* Many students wanted to face the speakers during Q&A time to hear them better but were afraid they would get stuck as they will have to turn the whole body of the Beam. In addition, P1 mentioned the difficulty of seeing artifacts on the table or a person sitting or standing and talking to them that were not on the level and facing the camera. He says: *"it's sort of like an awkward height. Sometimes you want to look at the page or look up to see the person talking to you. So it's kind of hard to like, see everything you want."* For P1, being able to adjust the height of the Beam would help him better interact with others in the classroom.

Six students pointed to the stairs as a limitation to classroom accessibility. P5 did not like to be carried and expressed a preference for disabled access ramps, *"It's weird, we cannot act normal like walking on the stairs"*. As for P3, he thinks: *"that's when you feel a little like [a] handicapped [person] with [regards to] movement."* Reliance on others to navigate stairs, according to P16: *"takes away of accessibility and is a challenge."* We acknowledge that these quotes reflect a lack of understanding about accessibility and use non-inclusive language, highlighting gaps in participants' awareness and sensitivity. We have chosen to present them here as is as their inclusion highlights the challenges disabled students will have with their peers regarding perceived deficits of telepresence robots. Future research could benefit from recruiting participants with experience working with people with disabilities or by requiring disability awareness training as a prerequisite for participation.

Participants (8) discussed how the Beam was slower than a human. P7 in a narrow hallway heard a classmate sayings *"I don't know if it's rude to pass a robot."* P7 compared this treatment to her experience of being a wheelchair user as she was crossing the narrow hallway, *"I felt like they wanted to ask me politely to move out of the way, now that I am thinking about this, this is all exactly how it feels like to be in a wheelchair...it looks exactly the same."* This goes back to William's [Williams 2023] point that robots are often perceived as disabled. The slow speed of the robot also impacted group work, as P20 described: *"I think everyone was moving up so quick. It takes time for the Beam to move a little... if you're present in person, you would quickly hop and see who's there and everyone starts teaming up quickly...So I was a bit concerned."* In the case of P3, team-members came to him so he does not have to move. He tied this experience to disability, he said: *"that's when you feel a little like handicapped [person] with [regards to] movement.., when I have to make other people repeat things for me and come to me."* The experiences of P7, P20 and P3 stipulate that not only they felt embedded in the robot but that it also impacts the treatment they get from her peers, leading to a diminished sense of normalcy and increased discomfort. Participants from Liao and Lu [2018a]'s study also noted the slow speed of the robots, which lead to some peers holding the robot to move from a space to another.

4.3 Impact of Telepresence Robots Accessibility on Classroom Inclusivity

Limitations in the telepresence robot's receptive and expressive abilities can significantly affect the remote attendees' ability to participate and engage with their classmates, ultimately hindering inclusivity.

Remote attendees may experience a different level of engagement and interaction compared to in-person attendees as they receive limited input. For example, P13 says: *"I cannot take part in the discussion as a robot because I don't really know what was said in the discussion... so I just sit here."* P11's experienced a similar limitation and expressed a need for more guidance and direction to fully participate in class discussions. He states, *"For some reason, it just didn't seem like a lot of things were asked of me. Like compared to being there in person, you know, I take on that initiative, but being virtual, it's like I needed more. I needed more help to tell me what to do because I wasn't sure what was happening most of the time."* Not being able to know what was said and what was happening can lead to remote students feeling excluded from classroom discussions and can ultimately impact inclusivity by creating barriers to participation and hindering the sense of connection and belonging within the classroom.

Furthermore, limitations in the expressive abilities of remote attendees can negatively affect their willingness to participate and engage with their classmates. For instance, P3 missed an opportunity to ask a question while waiting for his turn to speak to the instructor. He stated, *"They are talking to the instructor about something, and I didn't want to say a few things in the middle. But I didn't want to interrupt that conversation...I was just waiting for my time. But afterwards she moved on to another group."* In this case, P3 was unable to signal to the instructor that he wanted to contribute and was consequently unintentionally not given a chance to speak.

Moreover, the mobility limitations of telepresence robots can also hinder inclusivity, as noted by P13's comment that some classmates may not want to work with the robot as it requires additional effort to adjust their positions and ensure that the robot can see and hear properly. She explains, *"I think they don't want to work with robots because like the robot you need to move around a lot, like how to get into position like everybody and say to you, but I feel like you're in person. They don't need to really take care of you, but you are a robot they really need to take care of. It's like a, 'Oh, hey, you're here! Can you see us?"* This underscores the additional burden placed on classmates to ensure that remote attendees are included and engaged in the class, which can impact the inclusivity of remote attendees. P13's comment also implies that the mobility limitations of telepresence robots can make remote attendees feel like a burden or inconvenience, which can affect their sense of belonging and participation in the class. Finally, some remote attendees may encounter difficulties in forming teams due to their slower mobility, as highlighted by P3 and P10 who mentioned they could not move faster to form teams. Although instructors may acknowledge this issue and take steps to ensure that remote students are included, such as assigning a partner or grouping them with other students, the challenge of forming teams can still impact the inclusivity of remote attendees.

In certain cases, remote students had to balance and negotiate their desire to be included in the classroom discussion with their ability to access classroom content. For instance, P17 struggled with deciding where to position the telepresence robot to participate effectively in the class with their teammates. Initially, he placed it near his seat but realized that it hindered his ability to see the class properly. His classmates recommended that he move the robot to face them for better engagement. However, this adjustment made it difficult for him to simultaneously communicate and access class content, leading to a sense of exclusion. P17 said *"I don't know where I should place that beam. So I the first time I drive to the my seats, but then I think in that location, I might not be able to see my class. Right So my classmates recommend me to go the other way to like, face them to be more engaged in the conversation. it's really hard to communicate and be at the same. Like, same* *place and like discussing about a second topic... it's just like, I feel like left out."* This demonstrates how limitations in telepresence robot mobility can impact remote students' ability to engage in class discussions and access materials, reducing inclusivity.

Similarly, P3 had to confine himself to a corner of the classroom due to hearing challenges. He was unable to participate fully in discussions due to the loud classroom environment, which necessitated him to stay in a specific spot so that others could hear him. He says: *"At times just because the class was very loud. So, I had to confine myself to one like corner of the classroom so that the person who was talking to could hear me, okay, because the volume was a bit of an issue for the other person."* This limitation could impact inclusivity by causing remote attendees to miss out on important conversations or discussions in the class. Additionally, being confined to a specific location in the classroom to be heard by others could impact their ability to participate fully in group activities or discussions.

Despite the heightened awareness and responsiveness to the novelty of having telepresence robots in the classroom, our findings indicate that instructors struggled with ensuring inclusivity for remote attendees. As the use of telepresence robots becomes more common, instructors might adapt over time and develop better strategies to integrate these students, such as improved visibility of hand-raising and ensuring slide readability with adequate color contrast. However, there is also a risk that the initial novelty might wear off, potentially leading to a decrease in attention if instructors and classmates become accustomed to the robots' presence. Additionally, factors such as the perceived need for inclusivity and the institutional emphasis on accessible education can play significant roles in how instructors and students adapt over time. Future research should explore these dynamics by examining long-term changes in classroom interactions to provide a more comprehensive understanding of the impact of telepresence technology on teaching and learning.

In summary, limitations in the receptive and expressive abilities of telepresence robots can hinder remote students' engagement and participation in class, leading to reduced inclusivity. Remote students may have to balance their inclusion in the classroom with their access to classroom content.

4.4 Are Telepresence Robots "Disabled"?

While our data showed participants perceived both limitations and advantages to telepresence, it also showed how all members of a class engaged in strategies that could alleviate the Beam's limitations. Here we describe their strategies and discuss in the light of the theoretical discussion about whether robots are "disabled."

Strategies by the Beam operators: Participants mentioned mitigation strategies to their vision and auditory limitations. Some students moved to go closer to the front (P13, P19, P22, P4), however, others stayed where they were (P2, P20, P7) lest they distract their classmates or get stuck. P19 described the scenario of moving: *"I started out...little bit towards the back with my group mates, but it got to a point where I'm like, I can't even understand what's happening. So I ended up just moving way towards the front."* P22 moved too: *"after I arrived at the first row, and then I felt like oh, so even I am at first I still cannot read by just fell it okay I could hear."* The possibility of distracting their classmates was deterrent to move for some participants (P2, P7, P20). For example P7 says: *"And the visuals were difficult to see… I wasn't able to really see. .. I was a little nervous, like, oh, man, am I gonna have to disrupt the class and go up, roll out and get really close to the screen? And I didn't do it... I would have been a little worried that I get in somebody's viewpoint or interrupt the flow of the class or something."* The fact that the Beam operators were able to somewhat alleviate some of the limitations signifies that the telepresence robot is not disabled but have a mixture of both new abilities and disabilities. This follows Rode [2018, p239]'s framing that "conscious trade-offs between the affordances of my corporeal body and an emergent cyborg-self" emerged.

Classmates helping the Beam operators: In many instances classmates volunteered to help the remote students. In few instances the needed help was not received, which made the operators' task a little harder as they needed to figure out other ways to circumvent the limitations. P3 mentioned requesting a teammate to read a piece of paper as he could not read it himself for an activity, which helped them complete the task. P15 tells how she got stuck but classmates helped and she found that very nice. P3 mentioned classmates coming to him to form teams faster. He said: *" I tried to move somewhere else but they confined me to the corner saying okay, you don't move I moved to you."*

In few instances, the requested help was not obtained. Beam operators often need help to pick things up from their way. P4 told a story about a classmate not helping her removing a cord from the floor so she can move to a place: *"When I was trying to go to my seat, there was a charger cord. And I didn't know if I could go over it. And I was trying to talk to the guy who was sitting there. That's when I realized I was on mute. So he had no idea what I was saying."* Our video of the incident shows that P4's classmate looked up, and saw his charging cord on her way but went back to his task without moving it. P4 considered that: *" it was a rude thing... he clearly knew what my issue was and was just kind of looking at me."* Although P4 knows that her classmate did not hear her, she expected her classmate's pragmatic understanding of her situation would indicate her access needs. While P4 could have gotten where she wanted to be by knocking the laptop off the table, her adherence to the social norms to respect others properties resulted in her going the long way around to protect her classmate's laptop.

However, help is not always solicited: Others in some instances help but sometimes more than needed because they are unaware of the robot capabilities and limitations. P3 tells about a scenario where his classmates were directing him to where he was going. He said: *" I mean, he's directing me to where I want to go but again I he didn't know that I could see you and he's directing me in places where I fit ... I have a lot of functions, which probably they don't know that I can do...So unless I ask for help, don't come and help me ..."*. P3 comment about the robot limitations, feeling a little disabled and how classmates' assistance offset this, show that it takes more than the telepresnece robots and the operator's alliance to make the robot work in the context of the classroom. Classmates help can be sometimes key, but it is critical the robot not be moved without consent to respect remote user agency.

5 IMPLICATIONS FOR USE AND DESIGN

Our study sheds light on the accessibility challenges faced by remote students utilizing Beam telepresence robots in classroom environments. Based on these insights, we propose specific design and usage recommendations aimed at enhancing remote student participation. Although our suggestions are derived from experiences with the Beam robots, they are broadly applicable to other telepresence robots with similar specifications. We recognize that there are telepresence robots on the market with enhanced accessibility features, such as the ability to tilt and adjust height, like some models of Ohmni robots. However, the cost of these more advanced models is usually higher, which poses a significant barrier to their adoption in educational environments. This price difference underscores the importance of finding a balance between technological advancement and affordability to ensure the broader viability of telepresence robots in schools.

1- Use recommendations: Since there is an ever-growing amount of higher education institutions incorporating robotic telepresence in the classroom, we suggest the following guidelines to help enable accessibility to all robotic telepresence users. Ironically, many of these suggestions would also help make classrooms more inclusive of disabled students following Williams

[2023]'s suggestion that the needs of the disabled and cyborg could align. While our high level argument stems from William's argument that the needs of the disabled and cyborg could align, our recommendations stem from our own data.

Vision limitations: One way to combat this issue is for presenters to increase their presentation's font size, which can help accommodate attendees with visual impairments. Additionally, WGAC 2.2 contrast rules should be followed. Instructors could also make their presentation materials available to students in an online repository, so those joining online could access them there. All of this would improve the situation for visually impaired students as well [McGinty 2021].

Hearing limitations: Some participants commented on the inability to hear classmates that were not in front of them, especially during Q&A time. One way to address this problem is for the instructor to quickly repeat the question or comment from the classmate to allow the remote user to stay engaged. Again this could help hearing impaired students in the classroom, as well as, support the needs of English as Second Language (ESL) students [Schafer et al. 2021].

Mobility limitations: Rearranging the lecture room with limited obstacles is a simple way to improve the accessibility for remote users. Students should also be taught the kind of objects they can safely push out of the way with the Beam, for instance pushing in a chair to get it out of the way will not hurt the Beam's motor. Finally, as telepresence robots can not climb stairs, accessible spaces are key. Temesgen [2018], in their study of Ethopian classrooms talks about how physical obstacles like telephone poles, and utility trenches are obstacles for students with physical disabilities, thus spaces that are accessible for telepresence are more accessible for disabled people.

2- Design recommendations: We present design recommendations for telepresence robots in three categories. We recognize there is a wide range of features such as adjustable height displays and collision detection available on some robots, but our findings focus on the feature set of the robot we studied, the smaller domestic version of the Beam.

Vision limitations: As telepresence robots become more commonplace, improving the accessibility of their hardware and software is crucial. Integrating a higher resolution camera, along with stronger network signal, will provide a clearer view to the users. Additionally, providing more camera angles to the side or behind would provide peripheral vision more akin to what people expect in a classroom. This would especially benefit lower vision telepresence users, as the zoom feature could be used to compensate for reduced visual acuity.

Hearing limitations: Additional microphones on all sides of the telepresence robot, and the ability to switch between them could greatly increase the likelihood of hearing questions and comments of everyone surrounding the robot. This feature will allow the user to feel more comfortable in the robot, as the chances of missing important information is lessened. Moreover, if many people are talking at once, such as in the hallways or during a group discussion, there should be an option to mute certain microphone outputs to not overwhelm the user. Additionally, captioning is required to allow D(d)eaf/ Hard of Hearing classmates to communicate better with classmates. All of this must take into account privacy issues.

Mobility limitations: Obstacle detection sensors, such as Lidar or infrared, have been implemented on many current robotic systems. Similar technology can be integrated onto the telepresence robot, to help prevent users from getting stuck on an object. A simple alert can be displayed when the robot is too close to an obstacle. This function will allow the users to worry less about hurdles in their path and focus more on staying engaged in the classroom. Including more autonomous capabilities in the robot to navigate its way around the space and avoid obstacles, such as the ones available in robotic vacuum products to various degree and in mobile robots more generally, would decrease the cognitive burden of driving the robot for the user and allow them to attend more to the classroom content and activities. This is especially important when the user of the robot have physical disabilities which make navigating the robot difficult, or if the user had anxiety that might be exacerbated by fear of hitting something.

In summary, we underscores that designing classrooms for telepresence robot accessibility can create a more inclusive and accessible learning environment for all students, particularly those with disabilities. By aligning the accessibility needs of telepresence robots with those of students with disabilities, we not only address the challenges faced by remote students but also pave the way for a more inclusive educational landscape.

6 LIMITATIONS AND FUTURE WORK

We acknowledge several limitations in our study. Our recommendations did not cover the full spectrum of disabilities and their intersecting experiences. We chose this approach because, without established best practices for teaching children in classrooms, we deemed it unethical to focus exclusively on disabled students. This decision, however, narrows the applicability of our recommendations, given the potentially unique experiences and needs of students with these disabilities. While we hope our findings are a meaningful starting point for addressing disability and telepresence, we aim to deepen our understanding in future research, especially now that best practices for teaching students have been established.

Another limitation is the one-time experience of each student with the robot. This contrasts with the enduring realities faced by students with life-long disabilities, who may have developed specific strategies to address challenges, such as interdependence. The variation in experience between occasional and continuous use is a vital aspect future research should consider. Nevertheless, our data offers crucial initial insights into accessibility challenges, aiming to enhance long-term deployments for disabled users.

Due the logistics of studying within our own Informatics department, our participants were technologically savvy. It is essential for future studies to include a broader range of technological competencies, as not all disabled users are tech-proficient. This broader inclusion can uncover additional challenges faced during long-term use by disabled participants.

We conducted our study in Informatics department, which while a naturalistic study may not replicate the challenges of real-life telepresence in more natural settings like homes. For instance, high quality internet and immediate technical support might not always be available in real-life scenarios. Lastly, we relied on self-reported data, which could introduce biases, such as social desirability or recall inaccuracies. Despite our efforts to reduce these potential biases by conducting timely surveys and interviews and using screen recordings and photos to aid recall, this remains a study limitation

We view the limitations identified in our study as crucial opportunities for future research, particularly in broadening the applicability of telepresence technology in education and enhancing accessibility for students with diverse disabilities. In our future work we will analyze and publish our data of the student's opinions about how having telepresence robots in the classroom changes classroom experience. We also intended to interview teachers and to write educational technology papers on how to ensure this experience is a positive one. An essential area for future exploration is the integration of telepresence robots with hybrid instructional approaches. This integration holds the potential to mitigate issues related to auditory and visual signal degradation, thereby improving the effectiveness of telepresence in educational contexts. While our current study did not extensively cover this integration, it represents a promising direction for future research and development. Our goal is to identify best practices for incorporating telepresence technology into a variety of learning environments, ultimately making education more inclusive and accessible for individuals participating remotely through telepresence robots as well as for people with disabilities attending in person.

7 CONCLUSION

Our research shows telepresence robots are not wholly disabled, but have a mixture of strengths and limitations that users can manage for a new kind of robot-mediated interaction with both new disabilities and abilities. In this paper, we have detailed the challenges users faced in terms of visibility, audibility, mobility, spatial awareness, and social interaction. We have outlined suggestions for improving the telepresence hardware, and laid out emergent social best practices users have created to address them. Ultimately, we argue telepresence robots and their users both have new abilities and disabilities, and that many of the steps that would make education inclusive to telepresence robots would also improve accessibility for a host of students with disabilities and and those for whom English is a second language. This is a significant opportunity to ensure educational equity, but requires future work to enumerate best practices. Telepresence is a promising new educational tool, but these challenges must be met lest it be used as a new means of marginalizing and disabling students.

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