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Students' perspectives and experiences with equity, diversity, inclusion, and accessibility in online and in-person undergraduate science laboratory courses

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Abstract

Inclusive education strengthens the capacity of academic systems and addresses the needs of all learners. Although colleges and universities are embracing diversity and introducing inclusive principles into higher education policies and practices, there is scarcity in research exploring undergraduate university students' participation and engagement in science laboratories, especially among underrepresented and equity-deserving groups. Accordingly, this study explores students' perspectives on undergraduate laboratory courses and investigates best practices for creating equitable and accessible laboratory environments, both in-person and online. This study addresses the following research questions: 1) How accessible are online and in-person undergraduate laboratory courses to students? 2) What equity, diversity, inclusion, and accessibility (EDIA) barriers exist in laboratory courses? and 3) What support structures are recommended to ensure inclusion of all students in laboratory courses? A mixed methods design was employed to gather data using an online questionnaire and semi-structured interviews with 58 students in undergraduate laboratory science courses from diverse cultural, ethnic, racial, and socioeconomic backgrounds at a Canadian university.

Findings highlight that students considered online labs to be flexible, convenient, self-paced, relaxed, and inclusive with respect to aspects involving physical disabilities and language barriers. In-person labs were deemed fast-paced, yet valuable for technical skills and inclusive considering elements pertaining to collaboration, academic support, and communication with peers and faculty members. Students highlighted the following as common inclusion barriers in both online and in-person delivery formats: accessibility (physical and language), financial, and stereotypical barriers. Recommendations for improving lab accessibility were also included.

This research has significant implications for the design of laboratory courses and other experiential learning environments in higher education, particularly considering recent transitions and modifications in education. This paper will discuss implications related to the following sub-themes in the special issue: instructors' professional development, digital education, and quality enhancement.

Keywords: undergraduate science laboratories, digital education, equity and diversity, inclusive education, accessibility

Introduction and research rationale

Equity, diversity, inclusion, and accessibility (EDIA) principles are a priority across university agendas, policies, and teaching and learning practices (Moriña, 2017). As defined by the United Nations Educational, Scientific and Cultural Organization (UNESCO) (2017), equity embodies "ensuring that there is a concern

with fairness, such that the education of all learners is seen as being of equal importance"; diversity acknowledges "people's differences, which may relate to their race, ethnicity, gender, sexual orientation, language, culture, religion, mental/physical ability, class, and immigration status"; and inclusion signifies "a process that helps to overcome barriers limiting the presence, participation and achievement of learners" (UNESCO, 2017, p. 7). Additionally, accessibility can be considered as a subset of inclusion, whereby "inclusive education...aims to enable both teachers and learners to feel comfortable with diversity and to see it as a challenge and enrichment in the learning environment, rather than a problem" (UNESCO, 2003, p. 7). Although numerous opportunities for learning about EDIA principles are available, such as webinars, keynotes, book clubs, and seminars, applying these conceptual definitions into meaningful and transformative practice can be challenging (Rodriguez et al., 2022).

EDIA principles are applicable across all disciplines; however, previous research has highlighted the importance of supporting EDIA in STEM fields (science, technology, engineering, and mathematics) in higher education (Estaiteyeh & DeCoito, 2023; McGee, 2020; Ramiah et al., 2022). Singer-Freeman and Bastone (2019) argue that the pedagogy and programs that provide equal opportunities for students to graduate with STEM degrees must be intentionally designed to make degrees in STEM accessible to all students. When we encourage and promote diversity, our classrooms and laboratories become more accessible, engaging, active, inclusive, and equitable (Reese, 2020). An inclusive laboratory is a space where all students have a sense of belonging and can participate fully in activities. Students bring valuable, diverse experiences to learning communities, an asset that may be lost if students feel like they do not belong (Batty & Reilly, 2022). Making laboratory curriculum transparent and intentional is important to students' perceptions of science practices (Beck & Blumer, 2021). It was also found that undergraduate research experiences are one of the most crucial factors affecting students' choice of majors and career paths, especially for underrepresented groups, as research experiences have been shown to increase student engagement (Guo et al., 2021). Therefore, there is a growing need to understand barriers to EDIA, students' learning, and participation in laboratory courses, particularly as educational landscapes evolve, presenting new challenges and opportunities for both students and instructors. This was evident during the COVID-19 pandemic, which highlighted unique challenges with respect to online versus in-person delivery formats and existing barriers related to EDIA (Aucejo et al., 2020; Delgado et al., 2021). Despite its challenges, the COVID-19 pandemic inadvertently brought awareness to EDIA barriers, prompting individuals to explore and implement strategies to support students.

Considering the imperative to navigate EDIA barriers in post-secondary education, this research addresses critical gaps concerning student participation and engagement barriers within undergraduate laboratory course environments. The study explores students' perspectives within these educational contexts, in both online and in-person delivery formats, while also investigating best practices for creating equitable and accessible laboratory courses across Canadian post-secondary institutions. Accordingly, this study is guided by the following research questions: 1) How accessible are online and in-person undergraduate laboratory courses to students? 2) What equity, diversity, inclusion, and accessibility (EDIA) barriers exist in laboratory courses? and 3) What support structures are recommended to ensure inclusion of all students in laboratory courses?

Literature review and conceptual framework

An overview of online laboratories

During the COVID-19 pandemic, digital course creations and online simulations enabled students to virtually manipulate lab experiments and practice authentic experiences (Delgado et al., 2021). Hanzlick-Burton et al. (2020) explored how hands-on remote learning neuroscience labs were able to empower underrepresented students by providing them with independent STEM-based active learning opportunities. Moreover, according to Grout (2017), online remote laboratories can be used as an assistive technology to provide better access for individuals with unique needs. Virtual reality applications improved cognitive skills in experiments for students with learning disabilities (Elfakki et al., 2023), and students benefited from the incorporation of various technologies (Basham et al., 2020). Overall, online learning affords flexibility, convenience, and control over students' learning (Adekola et al., 2017). However, one of the main challenges reported in online learning has been communication, as the online environment does not adequately replace face-to-face interactions (Attardi et al., 2018). Communication is a critical element for in-person laboratories, which has been highlighted by several studies that emphasise the importance of teamwork and collaboration in laboratory learning environments (Sigaeva et al., 2020). Thus, the online experience does not completely replace the in-person laboratory experience, or the cumulative technical skills acquired throughout a laboratory course (Goudsouzian et al., 2018).

EDIA barriers in undergraduate laboratories

According to Ontario Human Rights Commission (2003), barriers to education can take many forms such as physical, technological, systemic, financial, or attitudinal. Systemic and stereotypical barriers include racism, poverty, disparities in health and education, lack of support, and lack of flexibility outside of the classroom (Lucy et al., 2022). In this section, we explore studies that investigated these barriers in the context of higher education science courses.

Accessibility barriers

Numerous accessibility barriers exist within educational contexts, posing substantial obstacles to the full inclusion and equitable participation of all students, especially those with disabilities. Common barriers for these students in higher education include lack of systematic staff training on the purposes of reasonable adjustments for students with disabilities (Little et al., 2023), lack of prior knowledge of faculty about a student's situation, lack of dialogue between faculty and student about possibilities of adaptation, lack of approach to disability in the curriculum, lack of accessible structure in auditoriums, and underestimation of disability (De Oliveira et al., 2022). Laboratory spaces introduce additional physical barriers, such as unclear and narrow aisles and pathways, cramped workplaces, and elements positioned too close together or too high to reach (Jeannis et al., 2020). It is also essential to highlight that invisible disabilities (e.g., dyslexia, attention-deficit hyperactivity disorder, and/or mental illness) necessitate various types of adjustments (Mullins & Preyde, 2013). Furthermore, feelings of not belonging can be amplified in a laboratory setting, given the pressure to perform, the introduction of new equipment, and a busy environment, especially for female students and individuals with disabilities (Batty & Reilly, 2022). Reported facilitators included faculty responsibility around communication and student engagement, accessible content delivery and inclusive teaching practices, physical accessibility and adaptive equipment, and mentorship (Sukhai et al., 2014).

Financial barriers

Textbooks are a common financial barrier for undergraduate students (Moorberg & Crouse, 2017). This barrier is even more significant among underserved students, including racial/ethnic minority students, low-income students, and first-generation students (Jenkins et al., 2020). Additionally, for online learning, it was found that some students may not have access to reliable internet connection or software tools due to either their socioeconomic situation or to living in rural areas with limited bandwidth (Harris et al., 2020). It was also evident that the negative impact of the COVID-19 pandemic was significantly more pronounced for underrepresented groups as lower-income students were 55% more likely to delay graduation compared to their higher-income counterparts (Aucejo et al., 2020).

Stereotypical barriers

Stereotypical barriers often manifest in ways that may not always be overt or intentional, yet their impact can be profoundly detrimental to those who experience them. Microaggressions are an example of subtle, yet harmful forms of discriminatory behaviour related to characteristics experienced by members of oppressed groups (Ramachandran et al., 2023). Researchers have detailed incidents of racial microaggressions, racial stereotyping, and other forms of racialized bias in STEM fields (McGee, 2020). Racic et al. (2023) suggests tips for building an anti-racism culture in higher education. This includes fostering student engagement in the implementation of anti-racism work as students' feedback has an impact on shaping curricular content and encouraging students to talk about their experiences of racism as this can help institutions recognize biases reflected in institutional practices and policies.

Therefore, based on all the above, universities must strive to address these equity and accessibility barriers by providing support to students. Examples include ensuring equitable representation of racially and ethnically diverse educators and other teaching support staff (Buery-Joyner et al., 2023). We know that teaching assistants (TAs) influence student outcomes by not only fostering scientific practice but also enhancing affective characteristics such as motivating students and creating a comfortable and enjoyable laboratory environment (Wheeler et al., 2017). TAs also impact the retention of students, particularly women and individuals of colour, in scientific fields. Undergraduate students tend to relate more readily to TAs than their professors, often due to similarities in age and social status (Gardner & Jones, 2011).

Methodology

Research design

This study utilised a convergent one-phase mixed methods (one-phase) design (Creswell & Creswell, 2018). The research team concurrently collected quantitative and qualitative data, ensuring parallel constructs were maintained. The data from each type were analysed independently, and the findings were subsequently compared. This study was a pilot research project and recruitment took place at an Ontario university in Canada. Data sources included online questionnaires administered to students in undergraduate science programs and semi-structured interviews with students in undergraduate science courses. Therefore, this approach facilitates comprehension of the phenomena by examining both the "whole and its constituent parts" (Cohen et al., 2011). Validity is enhanced through the corroboration or triangulation of data, utilising multiple data points from the same phenomena (Creamer, 2018).

Participants

The research team initiated participant recruitment by emailing all students in undergraduate science programs via respective faculty administrators and utilising social media platforms (Twitter, Facebook, and Instagram). Eligibility criteria included being a current undergraduate science student (e.g., Biology, Chemistry, Physics, Medical Sciences, etc.) at the Ontario university in Canada and having completed at least one undergraduate laboratory course in an online format and another undergraduate laboratory course in an in-person format.

In total, 58 students (41 women including transwomen; 16 men including transmen; one gender non-conforming) participated in the study. Participants were distributed across academic years as follows: Year 1 (5 students), Year 2 (11 students), Year 3 (18 students), Year 4 (19 students), and other academic statuses (5 students). The students had diverse ethnic backgrounds (two Black; 12 East Asian; one Indigenous; one Latino; seven South Asian; five Middle Eastern; 30 White Caucasian). Six students identified as a person with disability according to the *Accessible Canada Act* (2019), which defines disability as "any impairment, including a physical, mental, intellectual, cognitive, learning, communication or sensory impairment—or a functional limitation—whether permanent, temporary or episodic in nature, or evident or not, that, in interaction with a barrier, hinders a person's full and equal participation in society." With respect to socioeconomic status, 26 participants reported that they work part-time, three had caregiving responsibilities, and 25 students reported that they qualify for the Ontario Student Assistance Program (OSAP).

Ethics approval

This research acquired ethical approval from Western University's Non-Medical Research Ethics Board (Project ID number 121227). Informed consent was obtained from all participants.

Data sources

The research team developed the survey questions and interview protocols based on the literature and research questions. The questionnaire was conducted using Qualtrics only survey software and primarily utilised 5-point Likert scale items in addition to open-ended questions. The questionnaire provided preliminary insight about students' views of laboratory courses and how they compare online and in-person labs with respect to their motivation, engagement, competence, overall satisfaction, accessibility, inclusion, and workload. At the end of the survey, students provided their email and name if they wished to participate in an interview. The semi-structured online interviews detailed students' reflections and experiences in online and in-person laboratory courses. The interviews were audio-recorded via Zoom software, which provided the transcript of the audio-recorded interviews. The research team reviewed the transcripts for any errors.

Data analysis

The research team exported all data from Qualtrics and analysed the quantitative data using Microsoft Excel and descriptive statistics. Descriptive statistics encompass summary frequencies, including central tendency measures (mean, mode, and median) and dispersion measures such as standard deviation (Cohen et al., 2011). When interpreting students' overall attitudes, it's important to note that "strongly agree" and

"somewhat agree" on the Likert scale were considered positive views, whereas "strongly disagree" and "somewhat disagree" were viewed as negative.

Qualitative data were analysed separately based on the specific research questions, employing an interpretative analysis framework facilitated by NVivo 12 software (Merriam & Tisdell, 2015). Deductive and inductive analytical approaches were utilised in tandem to establish a comprehensive understanding of the phenomena (Mauldin, 2020). For the deductive approach, responses to questions concerning barriers were analysed using the aforementioned framework from the literature, which included accessibility barriers (e.g., physical and language barriers), financial barriers, and stereotypical barriers. Interview transcripts were imported into NVivo 12 software as cases, and participant's references to these barriers were coded. A matrix coding query was conducted to determine coding intersections and emerging patterns between the types of barriers and their reference in participants' interviews. Lastly, data were extracted to Microsoft Excel and a pie chart was created.

For the inductive approach, research questions related to comparing online and in-person labs and support structures for lab accessibility were analysed. This approach involved open coding assisted by NVivo 12, capturing the data with a phrase or concept, then the codes were compiled into more comprehensive categories, known as axial coding (Merriam & Tisdell, 2015). The research team discussed the codebook and clarified any discrepancies using the constant comparative method. Finally, emerging codes were combined into themes and appear as major findings in the results section (Creswell & Creswell, 2018).

Results

This section presents the findings of our study based on the research questions and focusing on the following three emerging themes: comparison of accessibility between online and in-person undergraduate labs, students' accounts of EDIA barriers in undergraduate labs, and suggested support structures aimed at ensuring inclusion of all students. Within each theme, we present students' survey responses, supplemented by illustrative quotes compiled from interviews. This approach, combining survey data with in-depth interview insights, facilitates data triangulation and strengthens the credibility of our findings.

Comparing accessibility of online and in-person undergraduate labs

The student survey included a list of items assessing inclusivity and accessibility in laboratory course learning environments. Students provided responses based on direct experiences in both online and in-person labs (Figure 1). In summary, results suggest that students favored in-person labs over online labs for reasons such as a sense of community, a sense of belonging/inclusion, encouragement of diverse perspectives, comfort in working/collaborating with peers, and ease of approaching/interacting with the teaching team. In terms of the availability of materials and resources offered, online labs were comparable to in-person labs.

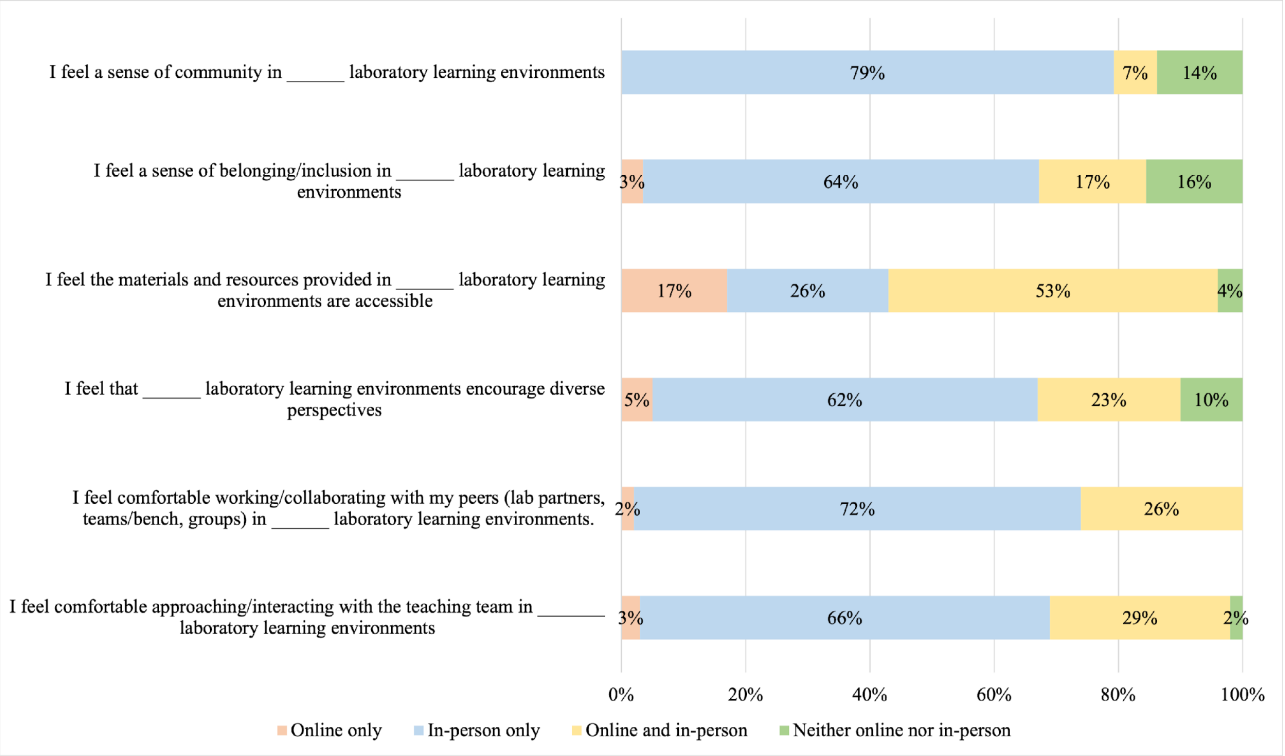

Figure 1 Students' survey responses comparing accessibility of online and in-person undergraduate laboratories based on their personal experiences.

Further analysis of interview data concerning comparison between online and in-person lab experiences within the context of EDIA supports the survey findings. When students were prompted to compare online and in-person undergraduate lab experiences, their interview responses yielded themes such as online labs being characterised as flexible, convenient, self-paced, relaxed, and inclusive, particularly in relation to addressing physical disabilities and language barriers. In contrast, in-person labs were characterised by a fast-paced environment, providing an advantage to develop technical skills, while also fostering inclusivity in terms of collaboration, support, and communication with peers and instructors.

The interviews also revealed individual perspectives about the online lab experience. A student who identified as physically disabled illustrated that she personally preferred the online lab for its inclusive nature for students with disability:

> …I would say that when my lab was online I felt as though I was at the same level with the other students. I felt like I was not disadvantaged in any way compared to them, so I did feel like, more like I belonged in the course…

This was echoed by another student who emphasised advantages of a blended laboratory environment, which includes both online and in-person components. She recounted her personal experience when she broke her ankle and had to rely on crutches for several months. The student explained how the hybrid model was advantageous, enabling her to maintain her academic performance.

In addition, another student provided valuable insights regarding the advantages of self-paced aspects of online labs:

> The self pace was very helpful to me as well, because I also have problems with concentration and just the amount of energy I have…It was very nice to be able to pace myself. Maybe watch the lab video and then do the entirety of the report. Later, or if it was a really long video, just watch a little bit of it and do the rest later. So…the online lab adds so much more accessibility and control for the individual…

For in-person labs, the analysis of the survey item, "I prefer to work individually compared to working with a lab partner" (M = 2.75, SD = 1.23), revealed that over half of students (56.5%) agreed to this statement, while 14% were neutral, and 29.5% disagreed. The interview responses further supported this finding, as students elaborated on additional dimensions of in-person communication. Most interview responses emphasised that what contributed to their sense of inclusion in the in-person setting was not primarily the physical layout of the labs, but rather the support, communication, and collaboration with peers and faculty. Specifically, students described how working with others and collaborating on assignments and lab tasks made them feel included. A common view amongst the interviewees was that being in a diverse classroom with diverse kinds of abilities made them feel more included. As one interviewee stated, "We have a diverse set of people with different ideas and different viewpoints, different backgrounds. And it's good to collaborate with them on scientific thought. Because they give lots of interesting ideas…"

EDIA barriers in undergraduate labs

Students' responses were examined within the context of the established framework, which includes three distinct EDIA barriers. Figure 2 illustrates the frequency of references to each barrier (accessibility barriers, financial barriers, stereotypical barriers) and the sub-components within accessibility barriers (physical and language barriers) as indicated by the interviewees. This section reports on comprehensive insights, along with sample quotes from interview data, as presented for each of these barriers.

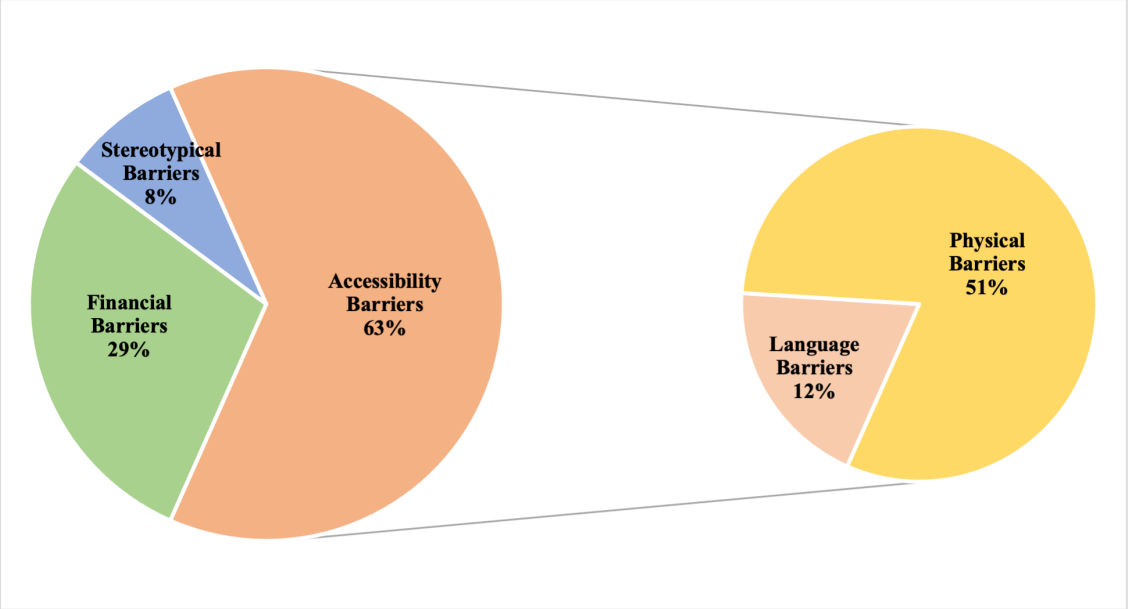

Figure 2 Students' interview responses on EDIA barriers in online and in-person undergraduate laboratories based on their personal experiences.

Accessibility barriers

As shown in Figure 2, during the interview, when participants were asked to "Identify equity and accessibility barriers in undergraduate laboratory course experiences," the students reported 63% of the total references were accessibility barriers of which 51% were physical barriers and 12% were language barriers. Overall, physical barriers were documented in over half of the references. Expanding on this point, a student shared:

> I met someone who is in a wheelchair, and they they're talking about their trouble…That's kind of what spurred onto my mind. Both are labs like, are they wide enough? Or, you know, we'll share the people with physical disabilities to get around, because sometimes it does get crowded. Sometimes the counters are tall, sometimes we have to do it because of safety reasons, and so on. So forth. But I'd say that's probably one barrier for people, especially with physical disabilities.

In this example, a student brought up the concern of lab layout, mentioning that many labs are divided into various stages. They suggested that having materials for the experiment in one accessible location could benefit students who struggle manoeuvring the lab. Additionally, another student stated that in-person labs were exclusionary to individuals with limited mobility, as they may find it challenging to move around during experiments.

Another student shared her experience of having an invisible disability, which made it difficult for her to access specific parts of the lab as she could not stand or sit for extended periods. The student also mentioned how it was physically demanding to use tools such as a mortar. Despite having an invisible disability, the accommodations provided were not sufficiently tailored for her needs. In this quote she illustrates:

> So, the people at the accessibility department and professors and people in the administration they know exactly what to do. But with someone in my position who has, you know, a less common disability, especially in invisible disability, and has more unique accommodations. I find that it seems as though the standard accommodations that are offered that would work for maybe most disabled students, or maybe people with learning disabilities just does not work for me. It's not enough for me. It's not comprehensive enough for me…

Shifting our focus to language barriers, some students commented that they faced communication challenges because English was not their first language. This barrier was more pronounced in in-person delivery formats. One student mentioned that using abbreviations for certain measurements was a language barrier. They expressed:

> Yeah, um, I would say at least in like first year in terms of like a language barrier thing. Um, they did like take the time in chemistry, to show us like a video just explaining everything but I mean it was all like in English. I think like at least, you know, having like closed captioning on the video would have been nice…

Financial barriers

Concerns regarding financial barriers focussed on the cost of textbooks for in-person labs and expenses related to digital tools and fast internet for online laboratories. To illustrate this point, 6 out of 19 interviewed students discussed the exorbitant costs of laboratory textbooks. One student stated, "If a student were to come from a lower socioeconomic status. I can. I could see how purchasing lab textbooks

would be very cumbersome, because they're often very expensive, and in addition to this, they can't be resold."

Moreover, nearly half of the interviewed students (8 out of 19) emphasised the need for fast internet and high cost of digital tools, which can adversely affect students with lower socioeconomic status. As one student said, "Everyone needs to kind of have good internet connection laptop and everything. And that can sometimes be a barrier for people from lower income families…"

Another student added: "Probably the biggest barrier is like a fast internet, which is, you know, very, very expensive for a lot of people in Canada…"

Stereotypical barriers

Some students expressed concerns regarding stereotypical biases. For example, one student reported that a TA showed some form of bias against her because of her gender:

> There was one TA that said to me one time she was like Oh, well, your glassware should be clean, because like…women normally clean, really well, and I was like I don't know if that's like something that should be said…

Another student discussed issues related to bias against women in science in general:

> …I've noticed some inherent biases towards women in science…I think that there is a little bit of disregard towards undergraduate women in science and undergraduates in general, because we're expected not to know anything. But yeah, there, there's a few issues there with equity for sure…

Moreover, some students felt that there was a hidden bias towards students who already had previous lab experiences:

> …A lot of the TAs or people who are supervising in the lab placed emphasis on people who perhaps did specialise programs in high school, and already had a lot of previous lab experience, and they got to do a lot more of the actual lab work, just because they had already had that experience, and were, you know, relatively good at it. And I think that really made me feel excluded because I do not do a specialised program in high school, and so I had a lot less lab experience previously. And that definitely made me feel like I was missing out on kind of the larger part or larger picture that was going on in the lab.

Additionally, there was a sense amongst interviewees that their written communication skills were putting them at a disadvantage compared to their peers. For example, a student explained:

> …Writing skills, and the expectation of prior knowledge in that capacity is a huge concern in terms of equity. In this program, there are people who have been fortunate enough to attend very expensive, very private like private schools, and have access to tutors and to individual support that have allowed them to learn a lot of skills very quickly, as well as not having to, you know, work two jobs to afford their tuition and can do that through high school as well. There are also students like myself who are, you know, requiring OSAP assistance, and have two jobs in addition to my work and I worked all throughout high school and didn't necessarily have those same kind of enrichment opportunities to practice a lot of these critical skills like strong written communication….

Students suggested recommendations for improving lab accessibility and for overcoming EDIA barriers in the future. This section outlines four key themes that emerged from interviews and survey responses: utilising blended environments; designing inclusive lab structures and materials; providing individualised accommodations and increasing staff support; and presence and representation of TAs.

Utilising blended environments

During the interviews, students were asked the question "now that you've experienced both types of labs (online and in-person), how do you envision laboratory courses in the future (post-pandemic)"? All students agreed on the importance of in-person lab environments for learning practical skills and for communicating with their peers, whereas the flexibility and accessibility of the online environment were suggested as an add-on to the in-person lab but not as a replacement. One student recommended that, "Basically, just to give like the flexibility part of an online laboratory to the in-person laboratory." Another student proposed:

> So, I definitely hope to see them return to in person or blended sort of model for people who aren't able to make it to lab. It's like those with physical disabilities or, you know, mental disability like just uncomfortableness, but being in a group of people, I think the flexibility of that is really helpful for the students…

Designing inclusive lab structures and materials

Students put forward recommendations to ensure that labs become more accessible and inclusive of all students. For example, one student stated:

> …They've been renovated. But you know you can't change the tables and things like that. So maybe in the future, like the next labs, can have some accessibility or things like that. Although it didn't happen in my lab…it could happen in the future and other people's labs.

With respect to creating inclusive lab material, a student mentioned:

> In terms of accessibility. A lot of the protocols that you'd have to do for the in-person labs work written. So, having an auditory version of the protocol accessible, might help somebody who potentially had a hard time reading either a learning disability or some kind of blindness having an auditory version would just give an extra aid to that student so that they could complete their lab successfully…

Providing individualised accommodations and increasing staff support

In one case, a student discussed a scenario involving his peer who had special learning needs and how the student was offered an accommodation accordingly. The student explained:

> But I remember there was a student who had dyslexia or something like that, and they provided him…I think, an hour extra for the lab, and they helped. Then the TAs were more, you know. helped him out with reading the lab materials and stuff. So that was one way I saw it, I guess, online, I know a bunch of people had accommodations. Who you know how, had also extra time to complete the lab, or something or the other.

Another student illustrated an accommodation that they witnessed in the labs, and this time the accommodation was offered by the professor:

> Actually, this comes to mind just because I've experienced, or one of my lab mates actually had this, who had a hearing disability like they weren't able to hear as well as others….like we would have to go outside to talk as a group, just because it was too loud in the group, or in the lab for us to hear her for her to hear everyone else…there was this device that she uses to, like, pick up on the sound a little bit better. It connects to her hearing aids, and she would have to. She was able to get that to the professor so that the professor could wear it around their neck, when they're talking. So that, like it picks up the voice a bit better. So that was, that was an accommodation for sure…

One student reported on an accommodation offered by the lab coordinator:

> …But one thing that was very helpful… the Lab Coordinator…when I was in person, she really made the lab experience so much better for me. She was so kind and understanding and if there was a certain part of the lab that would take a lot of time where I would just be waiting for something to happen, she would start it before I got there so then, when I got there, I could have the partially finished, product, and I wouldn't have to sit there waiting for 20 min., and she helped identify what were the most important parts of a lab, so that I could, if I had the ability to leave early, I could. So I would say that there are so so so many ways to improve accessibility...

Presence and representation of TAs

For the survey item "I prefer to work with the same teaching assistant as opposed to different teaching assistants" (M = 4.31, SD = 0.93), 84% of students agreed to this statement. This shows that students preferred to work with the same TA as they established a positive relationship. One student discussed how it was good to see that the university was hiring people of color and seeing the TAs in this position was very promising for her.

> In terms of like visible minorities….I don't really have much to say about that except like it is nice to see people that are teaching you that look like you …I think for me it's just like mostly seeing people who look like me in STEM, um, at least in chemistry like one of my teachers assistance was also like a black woman, and then like, I think, like in biology was the same thing like... really, for me, just helps me feel included just like when I see people who look like me also like beyond like the student body. The people who are actually employed by the university, whether that be like professors are like teaching assistants, it's just nice to know that like you know you're not the only one in one of the few so yeah for me like the thing that makes me feel the most included is when I see people who look like me, working in the scientific fields.

This view was echoed by another student who indicated that he belonged to a minority group as well and seeing the TA made him feel included:

> You know, in terms of equality when it comes to minorities like personally I have not never experienced an issue with that I mean, my TA even like she's also a minority like she's Chinese. And like you know obviously…I'm a minority as well like I'm Indian by origin, like, my parents came from India, but that has not been an issue at all like I've never seen. I've never been treated differently because of that and I think it's a pretty welcoming environment.

Discussion

The aim of this study was to extend current knowledge regarding how online and in-person laboratory delivery formats can support accessibility for students. Participating students reported EDIA barriers in undergraduate laboratory courses that are conducted online and in-person and provided recommendations for creating equitable and accessible laboratory environments in post-secondary institutions.

Firstly, for the theme related to comparing accessibility for online and in-person labs, students felt that in-person labs were more successful than online labs for factors related to sense of community, sense of belonging/inclusion, encouraging diverse perspectives, working/collaborating with peers, and seeking staff support. Interview responses corroborated these responses as in-person labs were found to be more inclusive than online labs for those factors. Online labs were deemed more inclusive for factors related to accessibility, especially in cases of physical disabilities and language barriers. These results are consistent with previous studies comparing online and in-person labs as it was shown that online labs could not completely replace in-person labs especially for factors related to face-to-face communication (Attardi et al., 2018) and real-life cumulative technical skills (Goudsouzian et al., 2018). Another crucial aspect regarding the advantages of in-person labs involves collaborating with peers and experiencing a sense of belonging within a team. This was evident in our study as students emphasised the importance of having nearby peers for collaborative work, asking questions, and clarifying concepts. Teamwork was previously documented as a factor that improved students' understanding and interpretation as it allowed technical concepts to be reinforced (Sigaeva et al., 2020). The collaboration and teamwork element were somehow missing in online lab components. That said, online labs in our study were still viewed as an accessible medium for students. Participating students emphasised the value of blended learning environments as online components were viewed as more inclusive of students with disabilities or injuries who were not able to physically commute to campus. Hence, our results expand on findings that online delivery formats were accessible and inclusive of students with physical disabilities and learning disabilities (Basham et al., 2020; Elfakki et al., 2023, Grout, 2017). Additionally, online delivery formats were shown to empower underrepresented groups as it improved confidence (Hanzlick-Burton et al., 2020) and sense of belonging.

Secondly, EDIA barriers reported by students were accessibility barriers including physical and language barriers, stereotypical barriers, and financial barriers. The physical accessibility of in-person labs was related to all aspects of the lab space and was a recurrent concern for all participants. Evidence shows that the inaccessible lab space was not welcoming for students with physical disabilities (Jeannis et al., 2020; Sukhai et al., 2014). Participating students in our study reported difficulties related to invisible disabilities as was seen in Mullins and Preyde's (2013) study. Regarding language barriers, it was suggested that videos be played with captions for students whose first language is not English. This is demonstrated by Sukhai et al. (2014) on the importance of ensuring accessible content delivery and inclusive teaching practices. For financial barriers in in-person labs, students discussed the high costs of lab textbooks. The financial strains were more significant among historically underserved students (Jenkins et al., 2020; Moorberg & Crouse, 2017). Additionally, access to online software and a strong internet connection was considered a barrier in online labs for low-income students (Aucejo et al., 2020; Harris et al., 2020). For stereotypical barriers, some students reported cases of bias towards women and high achievers. This broadly aligns with literature on microaggressions in STEM fields (McGee, 2020; Ramachandran et al., 2023). Moreover, students expressed concerns about how some students had extensive previous lab experience from their high school education which gave them an advantage to complete lab work faster. This strategy was deemed unfair as it made students without prior lab experience feel disadvantaged and they felt that they were not given the

chance to develop their skills. This argument is supported by Batty and Reilly's (2022) study as it was evident that the number of labs and hands-on experience was variable at the school level. This shows that university-level teachers in introductory modules should not assume prior knowledge and experience of laboratory work. Thus, our results suggest that teaching staff must provide equal opportunities for learning and practice for all students.

Thirdly, students in our study outlined lab support structures to ensure inclusion of all students. Recommendations for improving lab accessibility included utilising blended environments, designing inclusive lab structures, providing individualised accommodations and staff support, and presence and representation of TAs. Students suggested for blended environments to be utilised in such a way that the flexibility of the online laboratory be used in the in-person labs. From the results, participating students preferred in-person labs; however, the flexibility of the online lab was appealing for all students and was suggested as a solution for creating more inclusive laboratory courses, especially for offering special accommodations. Our study confirmed findings by Adekola et al. (2017)'s study as blended delivery formats encouraged independent learning and was easy to use. It was also suggested that physical lab spaces be more inclusive of students with physical disabilities as some tables were not accessible for students who need to use a wheelchair. An additional recommendation is that required texts have auditory versions for students who are hard of hearing to make the laboratory protocol more accessible to students. Furthermore, students reported individualised accommodations that they witnessed in the lab and were extremely helpful and thoughtful for their peers. For instance, supporting students with learning disabilities by giving students extra time and assistance to read the material, an instructor wearing a device that connects to the hearing aid of a student, and finally a lab coordinator preparing the experiment beforehand for a student who could not sit for long stretches of time in the lab. For establishing TAs and staff support, students expressed their preference to work with the same TA which shows that students build a relationship with their TAs. This is especially important and well-documented in the literature of EDIA. Students relate more to TAs because of similarities in age and social status. TAs also aid in retention of women and people of colour in scientific fields (Gardner & Jones, 2011). Students feel a sense of belonging when they see themselves represented by the people delivering the curriculum (Buery-Joyner et al., 2023). Creating a sense of community for students who are underrepresented in institutions of higher education is essential and faculty can play a role as cultural agents who support students' sense of belonging (Singer-Freeman & Bastone, 2019).

Implications and lessons learned

This research has significant implications on the accessibility of laboratory courses in the future. Students were encouraged to share their experiences and their understandings of EDIA in laboratory courses conducted online and in-person. This can further inspire institutions of higher education to put their practices and policies under the microscope and see how it impacts students, especially underrepresented groups. We present below the key lessons learned from this study as a list of items to make our findings more accessible to other practitioners and policy makers.

1. Online labs are flexible, convenient, self-paced, relaxed, and inclusive with respect to aspects involving physical disabilities and language barriers.

2. In-person labs are fast-paced, yet valuable for technical skills and inclusive considering elements pertaining to collaboration, academic support, and communication with peers and faculty members.

3. Common EDIA barriers in both online and in-person delivery formats:

   Accessibility Barriers: physical barriers included difficulty accessing parts of the lab, difficulty manoeuvring the lab due to tall counters and narrow aisles, and lab benches are not wheelchair accessible. Students whose first language is not English faced difficulties with language barriers, such as comprehending acronyms and the absence of closed captioning on videos.

   Financial Barriers: high costs of textbook and lab manuals for in-person labs and the costs of online applications and fast internet for online lab delivery.

   Stereotypical Barriers: gender stereotypes especially against women in science, biases towards high achievers, especially students with previous lab experience.

4. Recommendations for improving lab accessibility included: integrating blended learning, designing more inclusive lab spaces, providing individualised accommodations, and assembling a team of teaching assistants and support staff who are representative of diverse student populations.

Limitations and future directions

One of the study limitations is related to the generalizability of qualitative research. Despite the in-depth explorations, the processes and dynamics that occurred in the courses reported in this study are specific to the documented setting and study participants. One of the suggestions to overcome this limitation is by conducting similar research in other universities to expand the theories related to EDIA barriers and support structures. This would expand the scope of transferability of findings and would strengthen the claim to motivate educators and policy makers to recognize, challenge, and change accessibility barriers reflected in institutional practices and policies. Another limitation is related to the quantitative part of this study. The sample size can be expanded to be representative of a larger student population. The utilised survey provided an overview of students' views and was done to ensure triangulation of findings. Thus, future research can recruit a larger sample and may utilise online surveys for instructors to explore their attitudes and their recommendations for workshops and professional development opportunities.

Conclusions

This study explored how in-person and online laboratory delivery formats can support accessibility for students. The participating students reported EDIA barriers (accessibility barriers, financial barriers, and stereotypical barriers) in undergraduate laboratory courses that are conducted in-person and online. Blended environments, individualised accommodations, designing more inclusive physical lab spaces, and hiring support staff who are representative of diverse student populations were among recommendations for creating equitable and accessible laboratory environments. Therefore, researchers and practitioners must prioritise these recommendations and view them as an invitation for initiating change. Nonetheless, it is important to keep in mind that the transformation we aspire to achieve is a gradual process that demands both patience and thorough planning.

In harmony with the sub-themes of this special issue, this research has significant implications for instructors' professional development, digital education, and quality enhancement. First, the strategies that students found successful in promoting inclusion (see section on *Recommended Support Structures for Lab Accessibility*) can be the basis for instructors' professional development workshops and other programs aimed at enhancing educators' practices. Additionally, digital education was recognized as an enabler in supporting different models of educational delivery. Despite the reported challenges, online labs were also viewed as an accessible and inclusive medium for students. Finally, the exploration of students' perspectives and satisfaction with EDIA in online and in-person labs is essential for quality enhancement of undergraduate laboratories in the future.

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