Access Differential and Inequitable Access: Inaccessibility for Doctoral Students in Computing

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ABSTRACT

Increasingly, support for students with disabilities in post-secondary education has boosted enrollment and graduates rates. Yet, such successes are not translated to doctoral degrees. For example, in 2018, the National Science Foundation reported 3% of math and computer science doctorate recipients identified as having a visual limitation while 1.2% identified as having a hearing limitation. To better understand why few students with disabilities pursue PhDs in computing and related fields, we conducted an interview study with 19 current and former graduate students who identified as blind or low vision, or deaf or hard of hearing. We asked participants about challenges or barriers they encountered in graduate school. We asked about accommodations they received, or did not receive, and about different forms of support. We found that a wide range of inaccessibility issues in research, courses, and in managing accommodations impacted student progress. Contributions from this work include identifying two forms of access inequality that emerged: (1) *access differential*: the gap between the access that non/disabled students experience, and (2) *inequitable access:* the degree of inadequacy of existing accommodations to address inaccessibility.

CCS CONCEPTS

• **Human-centered computing** → Accessibility; • **Social and professional topics** → Professional topics; Computing education.

KEYWORDS

Accessibility, Graduate education, Computing education, Student with disabilities

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1 INTRODUCTION

In recent years, there have been increased efforts to support students with disabilities in higher education. Programs such as AccessComputing [9., 43.], DO-IT, Accessing Higher Ground and others have promoted programs, scholarships, and created support networks to boost disabled[1] student enrollment in post-secondary education. Despite such efforts, undergraduate enrollment does not translate into a strong pipeline of graduate students with disabilities in computing. The National Science Foundation's annual Survey of Earned Doctorates[2] in 2018 reported roughly 4000 students received PhDs in mathematics or computer and information sciences. Of those, about 2.9% identified as having a "visual limitation" and 1.2% identified as having a "hearing limitation." Unfortunately, prevalence of disability is often underreported, and the survey's ambiguous use of visual and hearing "limitations" may mean that instances of disability are not accurately reported. Despite programmatic and technological interventions instituted to help students succeed in post-secondary education [9., 27., 37.], numbers show that few students with disabilities obtain PhDs in computing, meaning less diversity in computing overall, particularly at the highest echelons of the technology industry.

To understand what barriers and challenges doctoral students in computing encounter, we interviewed current blind, low vision and deaf and hard of hearing (DHH) students or recent graduates, about their experiences in doctoral computing and related programs at US institutions. We focused on computing-related domains because such areas may involve software solutions, *e.g.*, automating alternative text and captioning systems to aid access to visual and audio content, and because of the knack for computing students to code solutions, whether students have a disability or not, *i.e.*, the practice of creating scripts for quick solutions. We found that inaccessibility for blind, low vision, deaf or hard of hearing doctoral students in computing and related fields manifests in two ways: ***access differential***, the gap between the access that participants and nondisabled students experience, and ***inequitable access***, the inadequacy of accommodations to address inaccessibility. We show how these forms of inaccessibility emerged across disabled graduate experiences.

2 RELATED WORK

Prior accessibility research in higher education typically addresses tools and applications (*e.g.*, making PDFs accessible to blind

[1] We alternate between person-first language "with a disability" and identity language congruent with Linton [30.], recognizing that individuals may have their own preferences to how they are referred to.
[2] https://ncses.nsf.gov/pubs/nsf20301/report

students) [10., 13., 16., 19.], accessibility of course instruction [11., 40.], or focuses primarily on K-12 or undergraduate experiences [6., 20., 26.]. We investigated accessibility issues specifically for doctoral students who identify as blind, low vision, deaf or hard of hearing.

2.1 Disability Support in Higher Education

Prior work addressed gaps in support for college students at the undergraduate level [6.], finding that self-advocacy is a predictor of academic success [18.], yet that university disability services and other campus resources vary in successful student support [17.], and academic advising for students with disabilities lacks appropriate training and guidance [34.]. Access support for disabled students throughout the college experience via outreach programs (such as the University of Washington's Do-It and AccessComputing programs [9., 27., 43.], Computing Research Association-Widening Participation (CRA-WP) Grad Cohort [12.] and the Richard Tapia (TAPIA) and Grace Hopper conferences), support students by providing scholarships, mentoring, and financial and technical support for high cost accessible technologies or personal help services. Such initiatives improved disabled student enrollment in computing majors [9.]. Yet, despite the availability of resources like disability services and the aforementioned programs, students typically bear the burden of proof of disability, and are responsible for knowing what they need and how to get it. Few institutional guidelines offer help about what students should look for and where [9., 34.].

2.2 Accessibility in Computing

Research focused on accessibility for college students target computer science education issues [10., 19.], including digital learning resources [16.] and course instruction [11., 40.]. Other work on accessibility in higher education focused on tools used in undergraduate experiences [2., 3., 6.], and are likely applicable in computing education broadly. Most efforts to address accessibility in computing target tool use [3., 4., 13., 24.], particularly at the undergraduate level [2.]. Other research focuses on making teaching and learning technologies and tools accessible [5., 7., 21., 28., 29., 35., 40.]. However, these efforts target end-user interfaces, which assumes that students shall be on the receiving end of research and technical interventions. In contrast, for example, few systems are accessible for a blind researcher to be the key driver of the development process (*e.g.*, Eclipse is the only known Integrated Development Environment (IDE) accessible to screen readers [1., 2., 3.], limiting students in collaborative opportunities if colleagues use a different IDE) [1., 39.]. Further, technical solutions target isolated tasks, while other aspects integral to the process are untouched, leaving research activities largely inaccessible (Eclipse is accessible, but plugins or input datasets might not be).

2.3 Graduate Education in Computing for Students with Disabilities

We focus on graduate experiences to investigate the shrinking pipeline to few doctoral students who identify as blind or low vision, or deaf or hard of hearing. Although previous research is devoted to undergraduate student success [2., 6., 20., 26.], not as much is known about how post-baccalaureate disabled students encounter and address accessibility outside of online masters programs [38.]. Meanwhile, graduate work differs from undergraduate education, yet comprises a constellation of barriers that prevent students from accessing resources and ultimately, achieving success [23., 34., 37.]. For example, gatekeeping (passive or active resistance to inclusion), lack of access to technical resources, and insufficient advocacy may stymie student progress (ch 3, [37.]), while perceptions of ability and lack of self-advocacy skills disadvantage students before they request or receive accommodations [14., 31., 41.]. Disability service responsibilities are typically shaped by legal requirements and undergraduate curriculum, not graduate level research activity, creating a gap in coverage for students conducting research [25., 32.]. The small number of disabled students in doctoral programs, particularly in computing, will negatively impact innovation and progress [15., 42.].

Diversity and inclusion of disabled innovators in advanced technology is more important than ever with the recent turn to intelligent systems in everyday technologies (*e.g.*, Amazon's Echo, or Uber's self-driving car initiative) [8.]. Higher education in computing domains relies on diversity in areas of expertise, technical competencies, and research-specific skills [9.].

3 METHOD

Our goals were to understand the experiences of graduate students conducting doctoral level research and taking graduate courses. We conducted an interview study with 19 current and former PhD students in computing and related fields who identified as blind or low vision, or as deaf or hard of hearing (DHH). We recruited participants who were currently enrolled, or enrolled in the last 10 years, in a PhD program. We recruited through personal networks and snowball sampling, as it was likely that graduate students might already know each other. We ceased interviews when we exhausted outreach to all suggested participants. Participants were compensated for their time.

3.1 Interviews

Interviews were conducted over the course of a year, with each conducted by one of three researchers. Interviews were audio recorded and lasted between 30 minutes to two hours. Interviews were conducted in-person, over video-conferencing, with ASL-interpreted phone calls, or on Google Docs, depending on the communication preferences of the participant. Although not all participants were students at the time of interviewing, we refer to them as "students" as our study reflects their time as a student, and to preserve anonymity.

We asked about experiences as doctoral students who identify as having a disability. For example, we asked about research and coursework, about what it was like to work with disability services, with faculty and advisors, with peers and in lab settings. We asked how they used tools to analyze data, write papers, read textbooks and research papers, and to conduct other aspects of research. Participants discussed activities related to graduate student life, including attending and giving presentations, attending conferences, preparing research for publication, and collaborating with others.

Table 1: Participants

Participant	Vision/Hearing Status	Years in Program	Area of Research
B1	blind	2	Computing
B2	low vision	5	Computing
B3	low vision	4	Computing
B4	low vision	3	Computational sciences
B5	blind	4	Computing
B6	blind	6	Computing
B7	blind	4	Computing
B8	low vision	3	Computational sciences
B9	blind	5	Computational sciences
B10	blind	6	Computing
B11	blind	2*	Computational sciences
B12	blind	2	Computing
D1	DHH	4	Computing
D2	DHH	5	Computing
D3	DHH	1	Computing
D4	DHH	2	Computing
D5	DHH	5	Computing
D6	DHH	7	Computing
D7	DHH	1	Computational sciences

*Years in program inferred from discussion during the interview.

3.2 Participants

Participants were in their first year through 7th year in a PhD program (Table 1), five participants had graduated or left their programs at the time of the interview. Five participants were international students. Gender representation among participants was slightly fewer women (15% in our data) than recent PhDs in computing (21% according to the 2018 Taulbee Survey[3]). We indicate participants who identified as blind or low vision with a "B" prefix and participants who identified as DHH with a "D" prefix. Table 1 shows years in the program at the time of the interview (including for those who were no longer students), and area of research, distinguished by focus primarily in core computing (*e.g.*, computer science or computing systems) versus in related fields (*e.g.*, computational biology).

The population of students who fit our inclusion criteria is extremely small, and we refrain from indicating individual gender identities, specific research topics, programs and institutions, citizenship or graduation status, and other identifiable information to maintain anonymity. Due to low representation of women, we use gender-neutral pronouns (they/them). One DHH participant identified as hard of hearing and the rest identified as deaf; we refrain from individually indicating status to preserve anonymity.

3.3 Data and Analysis

All interviews were transcribed and coded inductively using a grounded theory approach [22., 33., 36.]. Our data touched on as many aspects of graduate life as possible to get a sense of students' experiences. An open approach enabled us to draw out themes as they emerged from related but not obvious connections. For example, if aspects of reading created hardship for blind and low vision participants, our analysis highlighted challenges in the context of reading practices and also in terms of writing and publishing. Thus, our analysis led us to understand participants' engagement with accessibility within the larger experience of being a graduate student conducting research.

Analysis took place over the year during which data was collected. Three researchers independently coded the first five interviews, and then reconciled codes through continued discussion. Two coders continued to code the rest of the interviews as they were conducted, with weekly discussions throughout the analysis process to reconcile codes and discuss new codes and emerging themes. We show high level categories from our coding analysis (Table 2) that led to the two themes presented in this paper.

4 FINDINGS

Participants experienced inaccessibility in almost all aspects of graduate education, including in courses and conducting research. They reported mixed success obtaining accommodations for inaccessible research and writing tools, course content and lectures, research papers, and presentations. Courses were typically, but not always, covered by disability services policy, while research outside of class was not. Despite receiving accommodation, students encountered challenges dealing with proprietary tools or last minute course preparation, as may be common in graduate courses. In research, students pulled together available resources wherever they could get it, including from disability services, advisors, peers, or paid assistants.

Two main themes emerged: first, because not all aspects of graduate education fall under disability services' purview—and some

[3]https://cra.org/wp-content/uploads/2019/05/2018_Taulbee_Survey.pdf

Table 2: High level Categories for Access Differential and Inequitable Access

Access Differential	
Identifying and Defining the Accessibility Differences	*Compared to Sighted*: Sighted bridge (effort) to address inaccessibility, Limited available functions and features, Resource limitation, Lack of access/knowledge to math/graphics materials, Inaccessible assignment, Journal portals inaccessible, How tools are not accessible *Interpreter:* Delayed transcripts
Confusing Difficulty with Accessibility	*Inaccessibility:* is misunderstood; *Courses:* TAs don't accommodate; *Disability Services*: mistrusting; *Interpreter:* Avoid missing information
Effectiveness in Obtaining Accommodations	*General accommodation:* Course TA – inexperienced, No awareness on how to accommodate non-course aspect, Limited accommodation, No infrastructure to seek support *Disability services:* Require approval, Only for undergrads *Interpreters:* DHH population and availability, Learning domain knowledge, Hard to find w/ domain knowledge, Need for domain knowledge, Not for technical terms, Unable to request - notice time required, Hard to find w/ domain knowledge, Need for domain knowledge, Not for technical terms, Unable to request - notice time required
Accommodations Require Accommodations	*Inaccessibility:* Dictates choice and options, Alters what is doable, how it is done
Inequitable Access	
Ineffective Accommodation: Help is Not Really Help	*Disability services*: Hard to keep up with minutiae, Ineffective/Effectiveness, No plan, Don't know how to accommodate *Captions and Interpreting*: Good interpreter hard to find, Bad interpreter affects experience; *Faculty:* Help is not really help
Human Readers and Assistants	I Can/Can't Read, How academic papers fail to be accessible, Inability to access scholarly papers, Current solutions to address reading are inefficient/ineffective
Interpreters: Presentation and Communication	Dedicated vs. pool benefit, Confident in interpreter, Practice, For common terms, Request, Management, Scheduling, Bad interpreter experience, Mental error correction/double translating – tiring, "Dumb down" - simple words for unknown technical words
Acceptance	(Theme arose across multiple coded categories, including: inaccessibility around reading, courses, working with faculty and interpreters.)

aspects of graduate education in computing are at the forefront of cutting edge research—it was not always clear when participants needed accommodation and they found themselves responsible for identifying inaccessibility and then seeking solutions. Second, partly due to complexities unique to graduate study, participants wrestled with accommodations of varying effectiveness and quality. Thus, we organize our findings across these two themes: (1) access differential, the ways that participants identified and measured what was inaccessible to them, and (2) inequitable access, the effectiveness of accessible solutions, as many accommodations do not resolve issues but may incur overhead.

4.1 Access Differential Defines Accessibility

Participants described accessibility issues using a continuous comparative observation of how quickly or effectively nondisabled peers made progress. ***Access differential*** was the way participants described inaccessibility, the means by which they determined when an accommodation or workaround was necessary. Gauging access differential was also how participants understood unspoken expectations (*e.g.*, if sighted peers could read so many papers, so should participants), and guided persistence: The severity of an accessibility issue did not dictate task abandonment. Rather, participants took what they could get to maintain forward progress, abandoning classes or research tasks only after thoroughly exhausting all options.

4.1.1 Identifying and Defining the Accessibility Differences. Students were responsible for determining and defining their need for accessibility accommodation, and for self-advocacy, convincing others of this need. Outside of courses, participants had few formal guidelines for obtaining accommodations at the graduate level. Thus, participants identified inaccessibility by comparing what sighted and hearing peers accomplished, then, if possible, determining what accommodations could help.

Some of the most prominent differences emerged in tools participants could use. Despite engaging in highly technical and complex computing topics, participants experienced accessibility woes for basic tools:

> [My sighted peers] have the option–every one of them could be using a different tool to develop software. Somebody might want to use Sublime text, I can't... the point is that they could. They have the option, they can use a number of things. I get to use, like 1 of 3 things. Right, like, it's not the same for me... I've worked around to manage those limitations. But, that

> doesn't mean that it makes it equal. That just means that I've scraped bottom. –B1

As B1 mentioned, "it's not the same for me" compared to sighted peers because, despite having access to some tools, it does require some workaround to manage to adjust for the difference. Also, workarounds could be substantial, such as involving an entire analysis process:

> You can put [data] all on this graph where you just zoom around each chromosome and look like, oh, this position of the chromosome, there's like 5 genes here. . . And you can see that really quickly. Whereas I have to go and say like, I'm gonna download all of these files and I'm gonna run these commands to get the same information. . . I would have to go and run a program that says, how many genes are in this region. What are they? How far apart are they? What other types of data is in this region? So, it's a lot more one dimensional where you can be looking at a higher dimensional way really quickly on these websites. And that, you know, it's more of just a time thing. –B4

B4's description breaks down the steps for their analysis, but often tools meant to provide such access, such as screen readers, add another layer of skill that participants had to learn (*e.g.*, shortcuts), increasing the difference in effort that participants and sighted peers expended:

> You don't need to memorize those shortcut keys as a sighted person. Because most of the time you can do it with [a] mouse easily. . .for example, for you never click F6 or shift-F6 in PowerPoint to sequentially switch between panes because by a click of the mouse, typically you can click on your thumbnails and on your slide area. But for a blind person, they must know shift-F6 and F6 would sequentially to go on their status bar, then the note page, then the thumbnail, then the slide area. So, this is a necessity. –B3

B3's accessibility skills added an operational layer. Beyond added steps and extra skills, inaccessibility also emerged from limited capacity to engage in active reading practices when compared with practices employed by sighted peers:

> It's not that much comparable to highlighting or having notes on the paper itself because you as a sighted person easily find a note, and even if you need it, you can read the paragraph itself to see what was the context of your note. But to me, that is not possible because. . . Acrobat in PDFs–it's really inaccessible to have highlights and notes for screen readers, which is a shame, I dunno. I'm brave enough to call it a shame because Adobe had to do really a better job of that, to make that accessible. –B3

For DHH participants, the difference was in a lack of access to conversations, particularly impromptu interactions, with hearing peers. D4 lays out the gap, and its consequences, of access to conversations:

> Impromptu conversations—those that happen during walking, or in conferences, or just regular day to day social gatherings—are inaccessible for me. I have realized that these form a big part of the grad life—and in some instances, could lead to very useful collaborations and research insights, something that I completely miss out on. Reasons: Background noise, lack of facial cues, etc. –D4

In organized group meetings, courses, or seminars, inaccessibility was defined as caption or interpreter latency, which made it difficult to converse real-time.

> . . .there is a gap in access for deaf students in STEM because usually access is provided as interpreters or on-site captioning where those people may often lack the specific terminology familiarity. For example, sending the video to an agency gives them 3 days to make the captions better. –D7

Errors could also be an issue, commonly occurring in captioning but also when interpreters were unfamiliar with the domain. Interpreting requires familiarity with the signer's style. DHH participants noted the effort required to smooth interpreting experiences.

> One thing that always going to be constant challenge is having someone voice for me and then maybe they don't voice well, maybe they're not prepared. I have to give up my time to meet with them before to explain what I'm planning on saying, give them a preparation plan because for other hearing people, they don't have to do that. They don't need to prepare that way. They just show up, do the presentation and leave. Me on the other hand, I have to take that in consideration. –D3

Despite challenges, interpreters and captions were often the best available options, but required overhead to schedule. In addition to time and effort involved, social decorum added another layer of inaccessibility:

> . . .it's really hard to get an interpreter, . . . you have to request way ahead of time, give them advanced notice. and I always feel kind of guilty if I miss a meeting or I'm absent from a class because the interpreter's there for me and me only... if I don't go to the class, what is the interpreter going to be doing? They may have to wait for me basically and if I don't show up then they go back to the office. . . But, I always feel bad about that. It's not fair though because hearing people–they can miss whatever they want if they decide not to go or attend. –D3

In this section, we showed how participants estimated what issues were accessibility needs. In particular, they measured inaccessibility against peers, rather than subscribing to any other kinds of guidance, defining what worked for themselves.

4.1.2 Confusing Difficulty with Accessibility. Graduate school is expected to be hard, especially at the doctoral level. However, participants had to disentangle accessibility from difficulty to convey issues because professors, disability services, and others confused accessibility with challenging material.

> . . .you got this one component of: well are you unable to solve the problem or are you unable to even access what is necessary to solve the problem? . . . I'm sitting here trying to tell my professor, I can't access this. And he's looking at me like, you just don't know how to solve the problem. I go to the disability center and say, hey dude, I can't do this. And they'll be like, well, this is a hard course. No, you're not understanding. Like, yeah, the course is hard, but it's also – I can't even access what I need in this hard course. –B1

Faculty sometimes presumed participants *added* difficulty; not believing they had inaccessibility issues or assuming that assistive technologies resolved the issue. B5 was scolded by instructors and teaching assistants for not using the course-required tool because they were relegated to an accessible version:

> If you have someone who is using different tools, it does make it harder, and if they have a choice–like I understand where you're coming from. But, . . .you're just adding insult to injury when you say it without knowing that it's not the choice that I'm making.–B5

Similarly for DHH participants, the presence of interpreters conveyed that accessibility issues were covered. But DHH people rely on facial expressions to understand the sentiment of a conversation:

> My interpreters had to stand near the phone and interpret his voice. There was absolutely nothing for me to grasp that he was there, since I cannot hear. Just interpreters' words, with no other context such as vocal tone, facial expression. I told the professor about this but he didn't seem to understand that this was not accessible. If the interpreters are there, access, right? That's just a point I want to see emphasized. Access is defined by the student. –D7

Another way disbelief manifested regarded how much help participants sought. Human readers were a popular accommodation for blind and low vision participants, and it was helpful for participants to work with the same person for consistency in reading cadence, domain knowledge, and availability. Yet B12 had to defend their choice for a designated reader against accusations of cheating:

> I also had a reading assistant in mind. I was like, this is the person who is working with me, just do what you must do, get his paperwork in order. . . And they were like, "Oh, we have never done reading assistants before so we want to make sure you're not, this person is not doing your job for you." Okay, if that's what we're talking about, sure. –B12

Communicating issues was challenging when participants ran into misunderstanding, and sometimes disbelief, that their problems were accessibility problems, not just typical struggles with graduate material. These challenges stymied progress for students as they spent time and effort articulating their needs in ways others could understand, educating others about accessibility.

4.1.3 Effectiveness in Obtaining Accommodations. Typical disability services policy includes submitting requests before the start of term, but to do so, participants had to know what accommodations they needed. If participants could not define an accessibility issue, it was difficult to make a request. For courses and research projects with no precedent of disabled students receiving accommodation, every encounter with an inaccessible tool or task was a new one.

> She mentioned there was going to be an assignment where we would have to draw something. And I don't know why, I just didn't process that, or revisit it. I thought, well it's like writing code, so I'm like drawing with my keyboard, it'll be like–it'll be accessible. Well, I have never done computer science before, I wasn't thinking: how am I going to debug it, if it's a visual output of a picture. –B5

B5's instructor relied on them to make the accessibility accommodation request. But B5, new to computer science, could not wrap their head around what the visual output was, or what kinds of accommodations might address it. The instructor also did not know what accommodations might work. Thus, they could not make the appropriate request.

Even if participants knew what they needed, requests were often ignored or denied. In other cases, the culture of last-minute preparation could be a roadblock:

> In my research area, you cannot just listen to the presentations and get what the idea is... just listening was not useful. . . I've tried to reach the people and say, hey, can you please share your slides ahead of the time. But the point is either they are not willing to share their slides, or in many cases, I think they make their slides in the last minute. You know, [a] few hours before, so there is no way for them to send it, like, a day in advance [so] that I can review the slides and get prepared for that. I cannot change it–I mean, I'm even a person that waits for last minute. So, if I'm waiting for last minute, how I can expect others to be on time and send it? –B2

B2 acknowledges the norm in academia of late preparation means that few have presentations ready early. At the same time, the accepted practice of last minute preparations created a barrier for B2 to obtain slides.

In contrast, DHH participants were expected to request and manage interpreters or captioning early, despite no guarantee for accommodation. Low supply of sparse resources was prioritized based on demand across a range of events, which did not usually include PhD level courses:

> They typically give priority to events with more deaf people who are going to be in attendance. So, for example, let's say you have to pick between an introductory class for the first year course with 10 deaf people there or a PhD meeting, which is an important meeting, but with one deaf person involved. They're going to pick this one that has 10 people over the PhD one. –D3

In other cases, planning was not possible and other forms of workaround had to suffice:

> We all type on a [shared doc]. I have a transcribing app open in case people talk, but they all have said they like the doc as they can refer back to it in the future.

> We are still working on making this accessible *and* comfortable for everyone. For me, this is my normal mode of communication. I am used to typing. But hearing people are often used to hearing themselves or others talking. –D7

Just like courses had inaccessible tools that blind and low vision participants could not use even with screen readers, successful interpreter scheduling introduces challenges if interpreters are not qualified:

> One time [university] gave me an interpreting student (not even graduated yet) for a MS/PhD level course and he quit a week later. There should be no excuse for putting such a new interpreter in that situation because it's bad for the student who is embarrassed and has to quit the class and I don't get full knowledge of what is being said in the lectures, and need to get used to a new interpreter once there is a replacement. –D2

Our findings show that students expended energy in ensuring that they received accommodations, often having to adjudicate whether or not a solution met their needs. We emphasize that assessing accommodations added to effort needed to manage responsibilities and tasks.

4.1.4 Accommodations Require Accommodations. After participants identified an accessibility issue and accommodations were fulfilled, they still encountered challenges to bridging accessibility. Blind and low vision participants noted that using alternative tools or employing sighted help took more time, meanwhile, DHH participants reported extra time and effort to coordinate captioning and interpreters.

> I am usually ok talking one on one, but group meetings are a big challenge. First, it's hard to get captioning in case the group meeting was scheduled in a short notice (a frequent occurrence). Second, even if I do get captioning, it's not natural– I have to balance my attention between looking at the speaker, the captions and sometimes, visual materials, such as the lecture slides. Third, captioning has a significant delay, which again, is not natural for a conversation. –D4

Working with interpreters was key to addressing individual style and to maintaining communication accuracy for the complex domains that participants worked in:

> If I don't prepare then the interpreter likely is going to just read what I provide for them on the paper but I want them to look at me say what I'm signing. I don't want them to read my notes verbatim. . . So, that's one thing that is frustrating. I think for graduate students, especially PhD students, typically you work on advanced things, more specific and not general knowledge. So that means if I have an interpreter there, that interpreter might struggle to interpret what they're hearing because they're not understanding the content. They are just hearing and interpreting, hearing and interpreting. That's really hard for them when they don't know what the content is. –D3

For blind and low vision participants, workarounds might address inaccessibility but could take more time or effort. Workarounds were not always effective. B2 was given additional exam time, but an extension for a four hour exam was unrealistic:

> . . .it was advanced algorithm design, and I told him, that, okay I have extended time for the test, but assume that I have to sit down for 8 hours and–I mean, after 2, 3 hours, your brain is not useful to think intensively. And, he was breaking down the quizzes and exams, for example, if the actual exam had 4 questions, he was breaking down into 4. interestingly,. . . he was designing unique questions for me. But when I was comparing my questions with other students' questions, the difficulty of the questions were exactly same. So, he was spending time to do [that]. –B2

We note that the extent to which the accommodation—additional test time—was effective, also depended on the additional accommodation from the instructor, who created new questions just for B2.

In situations without accommodation, participants often sought their own ways to address inaccessibility. Many created their own scripts or devised their own workarounds. B9's sighted colleagues inferred meaning from analyzing visual data, meanwhile B9 created scripts to achieve similar analytic progress:

> I used a variety of in-house scripts, which I wrote to pull up various pieces of information from very large text files, which were our output files. Then, my sighted peers would pull those files up and look at them on the computer screen. . . and actually visualize the structures they studied. –B9

B9's scripts were useful for sighted peers also, a common side-effect that other participants also observed. B4 re-organized data using manual strategies, such as spreadsheets or tables to conduct data analysis:

> That's pretty simple, but when you get in higher things, um, it can be harder to display data in a way that is as fast to interpret. So I might have to put things in big tables and scroll through all of them or think of specific questions to ask about my data to get at the info that I want, which–it takes a little bit longer but you know, you do learn your data better that way than just putting something in like a big histogram and just, like, saying, okay this looks that way. –B4

In other cases, participants resorted to manual tasks as an accommodation. Doing so involved brute force task analysis, for example conducting word-by-word analysis in Excel in lieu of qualitative analysis tools.

> Dedoose is good for qualitative analysis, . . . And then the installer is inaccessible. . . How do you do qualitative analysis without Dedoose? . . . But, yeah there was somebody else who was luckily using Excel, who was not visually impaired. . . So they were like, "Well, maybe you want to do it like this. This is what you need to do." Then I sat down and figured out an Excel

> spreadsheet format that might work for me, and then did it. –B12

Despite dispensing time and energy to work around inaccessibility, participants still had limited access. These micro-accessibility issues built up, and for those involved in the long-game of a PhD, the lost time in an overloaded graduate environment measured against the productivity of peers was not trivial.

4.2 Inequitable Access

Accommodations provide access, such as when a screen reader can read text on a PDF. But simply having accommodation does not itself mean access. If a PDF has images that lack useful alternative text, the information gleaned from graphics and tables are not accessible and additional workarounds may be needed. In this way, a second theme emerged from our data that accommodations varied in their quality and effectiveness to bridge the access gap. ***Inequitable access*** underscores the degree to which accommodation actually addresses (or does not address) accessibility needs, and emphasizes the risks to poor performance or slow progress when inequitable accommodations make more work for students.

4.2.1 Ineffective Accommodation: Help is Not Really Help. As detailed above, obtaining accommodation was challenging when difficulty was confused with accessibility, or when participants struggled to articulate accessibility needs. Thus, *receiving* accommodation should feel like a win. However, our data shows that accommodation may not have empowered participants to be as productive as peers (*i.e.*, bridge the access gap):

> She had the website, she was saying that, I posted question [sic], you have 30 minutes to answer. Then I reached. . . her and said that, hey, I mean, 30 minutes is not enough for me to even just read the question. Even to locate the website login... put the password and then read the question and answer. It was like, you know, [a] one sentence question and the answer was so easy and straightforward, but I didn't have time to like read it. –B2

As in B2's example, screen readers or Braille displays that blind and low vision participants used were not helpful if the medium to be accessed (in B2's case, the quiz website) cannot *be* accessed.

In writing, although Word might be accessible with JAWS, the plugins for reference tools might not be, triggering the need for more workarounds:

> Reference management tools are not accessible. . . Mendeley, or Zotero, these are not accessible. So I have to keep, somehow manually keep track of all the references, my notes about them, like keeping track of literature is hard. I have to create a folder where I have a PDF, and then a Word doc with the same title so that I know that these are the notes corresponding to this paper. And when I want to insert references in Word, it's painful because none of these plugins are not–none of these tools are accessible so I have to either do everything manually or just switch to LaTeX and Overleaf, oh my god, yeah. –B12

We recall that DHH participants expended much energy managing how they communicated with ASL interpreters.

> Sometimes the quality of the interpreters here is very hit or miss. Mostly, the interpreters are very good at translating from spoken English to ASL, but from ASL to spoken English, finding a good one is very hard to find. Many times I have noticed (since I can hear a little and read lips) that what they said was very different than the message I wanted to convey and I would have to stop and correct them and this can throw me off my flow if I am giving a presentation, for example. –D2

In addition, the cognitive load required to visually follow and understand interpreters took its toll:

> People will think that accessibility means bringing in ASL interpreters. But at the graduate level, that doesn't quite always work, especially in STEM. ASL interpreters CAN stay with you and work to learn your field, but what happens if they leave to go to another job? Even if they stay with you all the way, it's still exhausting to do the double translation, and that reduces equal accessibility because you're still needing "accommodations." –D7

Participants commented often on various modes of preparing, such as working with interpreters, working out course accommodations early, and fielding ad-hoc and delayed needs such as when instructors for graduate courses were not prepared in advance:

> One of the big challenges that I always had at school was, okay, I need this book, I need this paper, I need to read this, I need to read that. Um, sometimes course materials were like scanned copies of text, professors would like just to scan a portion of the book, send it to the class, maybe one night before the class begins (laughs). You know, PhD-level classes, right? So, that was a challenge. –B3

Doctoral level reading expectations are quite high. Participants had mechanisms to read print, but the sheer volume of required reading (often dispensed at the last minute, as B3 mentioned) for coursework and research piled up quickly:

> ...in PhD courses especially—if they can tell people, like the students, what materials or what articles they're going to read. . . for the class a little in advance to possibly be able to somehow figure out the accessibility of those articles ahead of time. . . Once the course starts, there are so many assignments, so many readings and so many courses. . . it becomes really very challenging and time consuming to convert the material at that stage. –B10

Reading research papers constituted many issues that blind and low vision participants reported, they spent a lot of time and energy gaining access to journal portals to download material, access print, images, and equations in the texts themselves, and to make notes and highlights as they read. Next, we show how these barriers contributed to inequitable experiences.

4.2.2 Human Readers and Assistants. Reading is a key part of graduate student life, and all blind and low vision participants mentioned struggling with accessing research literature. Human readers were a popular option, and were typically students employed by disability services to read aloud to participants. Human readers could also be lab-mates, friends or family members. As with any resource, human readers required scheduling and management:

> Screen readers aren't the best at describing figures in papers. Authors who write those papers aren't necessarily the best at making their figures uniform enough that I can read them myself and make their captions descriptive of the figure because in many ways they were using the figure as a means of having to use less words in the paper. I would have to work with my colleagues and with assistants who I hired to read papers and really understand them. That's another tool issue. –B9

Using human readers involved a process of at least trying to read the paper first, then gauging the level of inaccessibility and the need for help:

> It used to be hard in that case, so I used to convert it to text form and then try read it, and if it's really very difficult for me; if there are many tables and I can't make sense of it, due to the size of the table and a lot of images and everything, then I had to take sighted help. –B10

Human readers required management and time, and in B2's case, were mediated through disability services. This relaying added a time delay:

> I took a blockchain class. And the instructor had some papers to read—and [disability services] were just working with PDF files and Adobe and sending back to me. And I first thought, I mean, early weeks, I tried to describe–for example, they were not making the equations accessible. And they were saying, okay, whenever you paste equation [sic], we'll send you a human reader, and he will or she will read it for you. And I was saying, I cannot recognize which ones I am missing—the equations—because that's stupid–[in the] middle of the [term], I gave up and I decided even not to respond to their email. –B2

To fulfill the request, B2 had to send the errant equation to be translated and sent back. However, screen readers did not recognize equations in the document, so it became impossible to send anything. B2 continues to explain the ineffectiveness of a process mediated by a third party:

> When you're doing research, [in the] middle of . . . reading or writing code, you need something, and you need to solve–for example, I'm writing code, and I need to, you know, check something or read something, I cannot send an email to [disability services]. . . hey please schedule a human reader for me, and then. . . I pause my coding or reading and that person comes and reads the equation. I mean, that's a stupid scenario, but that's what they offered to me. –B2

Reading material of PhD students is complex and dense. Having a human reader could be difficult if the reader was not familiar with the content (e.g., undergraduates are inexperienced at interpreting images and graphs). One way to combat inexperienced readers was to "train" human readers to know how to describe and interpret figures, math equations, or biology and chemistry diagrams, etc. However, training takes time and effort, and requires a committed reader. Participants attempted to secure a such a person as a reader for this purpose:

> We had an undergrad working [with us], . . .and [I] said, I want this person to be my assistant at any time that I can use, and you tell me how many hours I can actually have him and you pay. So, that a little bit resolved the problem, and it made it better because I could just rely on one person and he knew me better. He got used to my habits, what I needed. –B3

When participants had difficulty coordinating with disability services, they instead chose peer individuals with shared domain expertise:

> Yeah, it works good since there's about 8 or 9 people in my lab and we all do similar things, so they can interpret the same text of graphs. It was much harder to do that in undergrad when I was trying to read stuff, and I would have a student who was hired to work at disability services who, you know, didn't know anything about biology. –B4

Lastly, participants working with human readers were aware of what they were asking of another person, and they bore some self-consciousness about their continuous need to read:

> This is a person converting my text so I also want to be cognizant of what are the challenges that the team is facing. . .but yeah, end of the day I'm a student, I need things. So I was like, let's just set up a direct communication channel if you're fine with it. –B12

Working with human readers revealed multiple levels of accommodation issues that participants struggled with: they had to demonstrate their need for a reader (usually by first finding an inaccessible document and trying and failing to read it). Then, they had to convince others (faculty, disability services) that an accommodation would help, and then arrange to work with one. Arranging one could take considerable effort, and may not be worth a few words' access.

4.2.3 Interpreters: Presentation and Communication. Whereas blind and low vision participants encountered issues gaining access to print, DHH participants described challenges accessing live and recorded presentation content. Attending and giving research presentations was a key part of graduate life—whether as routine seminars or at conferences—and participants spent considerable time and energy ensuring accommodations, whether by ASL interpreters or captioning. But for presentations that occur less consistently than regular events (*i.e.*, classes or lab meetings), obtaining interpreters was challenging:

> For presentations, I actually was interested in a few this year but since the flyer. . . came the day of or the

> day before, I could not request interpreters since they require 24 hour notice. –D2

Accurate interpretation of complex technical material could be hit-or-miss, and for some, unreliable and poor experiences deprioritized attending talks altogether:

> I don't attend that many talks. When I do, I will often have an interpreter. But it can still be very difficult to learn from a talk unless I know the material beforehand and I don't think it that useful for me to attend many talks. I do attend a few though. But for the most part I would prefer to just try to keep programming and working on my own and getting my next directly relevant, like doing something that's more directly relevant to my own work. –D5

However, conversation includes communicating back, and due to nuances in language, DHH participants spent considerable time managing their communication style with interpreters when they used them:

> . . .the interpreter, their preparation, . . . I have to give up time to prepare with them for the meeting to make sure that they're saying what I sign correctly and accurately and to make sure that they know what happens, what's going on. –D3

Despite logistical and communication management challenges, interpreters were preferred and often worked well for DHH participants:

> I am generally happy with the quality of the services I get although sometimes I will need to work a bit harder to find the right interpreter for me. Once I find a good one there are no issues. –D2

Scheduling interpreters was difficult because supply and demand sets priorities, and there are few DHH PhD students. Interpreters served as an information and communication conduit and participants were aware that interpretations needed to be accurate for the complex domains they studied. Interpreters represented participants' "voice" in everyday research conversations and high stakes presentation venues alike.

4.2.4 Acceptance. Inaccessibility manifests as trial and error. Locating research papers may not be a problem, but downloading paper after paper only to find they are not accessible by a screen reader, to be saved until a time can be scheduled with a human reader, can add time and stress. Yet, participants continued attending courses, submitting assignments, conducting research and publishing papers with limited access to helpful features. They conducted research while reading text but not understanding images, and after skipping presentations when no interpreter could be scheduled. We note, however, that participants did hit limits and accepted what they could or could not do, taking whatever they could get.

> If I'm reading a paper for example, you know, I can read the figure legends in a paper, and get maybe 75% of what's going on, but I can't judge for myself, say, if in a figure legend they say we observe that this is a greater effect than this is. Then I'm just having to take their word for it and I can't look at their graph and say, I don't believe your conclusion there. –B4

In addition to accepting sub-par access to information, participants persisted despite a lack of sufficient accommodations:

> I think it was assignment 3–we were supposed to get through 18 levels. Um, I made it to level ten. Because it got to the point where there was just–there was almost no way to move forward without access to some of these higher level tools. At least as a blind individual there was just–I mean, . . . I didn't know what else to do. And I'd talk to friends and [they're] like oh, I used this, this and this. . ..Fine, I have no idea what you're talking about, dude. . . (laughs), I can't do those kind of things. So, um, of course, I had to take a hit on that. –B1

When participants and instructors could not resolve accessibility issues, participants had no option but to "take a hit," or drop the class.

> I contacted the instructor. . . and he was on board, I don't think he wanted me to do bad in the class. But it became very clear that there was like no [tutoring lab], there was no TAs. . . there was no section, there was no support systems in place, and then I started finding out that a bunch of the tools we were using just weren't accessible at all. And I kind of just gave up in the middle of the [term], I was like I don't want to do this anymore. And I quit the class. –B5

In other words, participants realized they hit a ceiling regarding how much they could progress within a given timeframe or accessibility limit, and they accepted the consequences, knowing that gaining access was unlikely to ever occur.

> It's sort of the same challenge regarding the interpreters. So I dropped out of all of my classes since it was too exhausting to follow. –D7

We note that most participants accepted lower grades or scores long before abandoning tasks. However, dropping courses and abandoning tasks was a common occurrence and often reflected upon matter-of-factly because students recognized it was not a limitation of their ability, but the limited capacity of access that disempowered them from continuing.

5 DISCUSSION

Our interview study found that blind and low vision, and deaf and hard of hearing doctoral students in computing experience common challenges to accessing course content and tools [17., 18.]. However our findings also showed that accessibility issues were defined by the gap between participants' and nondisabled students' productivity, as discerned by participants' own experiences. Their assessment of what was needed to effectively progress in their programs was in response to the vacuum of support left when disability services offered little guidance or policy [38.], particularly for research. Studies show that obtaining access to accommodations is fraught [31.], especially with concerns of being misunderstood [14.], but less is known about navigating barriers within students' wheelhouse. Our study shows that computing students utilized tech-savviness to address accessibility inequities as often as they did to conduct experiments, highlighting the ineffectiveness of accommodations,

even at the highest levels of innovation. Our findings show participants were disadvantaged due to access differential and inequitable access, even with accommodations.

That accessible solutions require additional ad-hoc accommodating on the part of the student shows that graduate education is not effectively covered by current disability services policy or institutional systems that should help students (course instructors, peer communities, or advisors). The status quo insufficiently met student needs, regardless of effort [37.] and, our findings show, led participants to develop their own ad-hoc accommodations. Expending effort to advocate for ineffective and inefficient accommodations [14., 31., 41.] further burdened participants to concoct "band-aid" solutions—*e.g.,* coding their own scripts as workarounds—sending the message that doctoral students with disabilities ought not to be the ones conducting cutting edge research in a university setting. When they received accommodations, accessibility issues were likely considered "solved," meanwhile participants struggled to make those accommodations work, training human readers, scheduling interpreters, and adding additional time and effort to their research tasks. Beyond misperceptions about disabled graduate students' capabilities [14., 37., 41.], our study shows that mistaking accessibility with difficulty and misunderstanding accommodations manifested a presumption that students with disabilities do not inhabit the doctoral sphere.

Despite these inequities, participants persistently address accommodation issues, demonstrating their right to conduct research and to the privileges associated with being a doctoral student. Whereas their challenges were not unlike common issues covered in accessibility research, *e.g.*, inaccessible PDFs [13.], the high-stakes environment of doctoral research, alongside ambiguous expectations, created a chasm of its own kind of graduate-level inaccessibility. Indeed, recent events emerging from the CHI community[4] documented inaccessibility and highlighted inequities among the research community at-large, emphasizing how the status quo continues to disempower blind, low vision, and DHH doctoral students.

Future work should reflect on opportunities to support and empower students to facilitate accessibility solutions that best work for them, throughout all aspects of their graduate experience from coursework, through to presenting at research conferences. Institutions and communities alike must oblige discrimination law and push for organizational change in research collaboration, conference organization, and even in hiring practices. Policies and processes should also be examined to improve student support in conducting research, including making domain specific tools accessible (*i.e.*, MATLAB, NVIVO, JGrasp, Dedoose, LaTeX, Word, PDF, Zotero, Mendeley, and Qualtrics, to name a few), and offering scholarships and funding for personal assistants and other assistive technologies.

6 LIMITATIONS

Our study is limited by the small number of participants and the narrow scope of the investigation, focusing on experiences for blind, low vision or deaf and hard of hearing students. Interviewing current and past students biases characteristics for those who made it to graduate school, and we refrain from commenting on barriers that prevent admission to prospective students. We hope to gain a broader understanding of how students with other kinds of disabilities experience graduate school, but intentionally kept our focus narrow to enable a deep exploration of students' experiences. We are also limited to findings unique to the doctoral student experience, thus we did not include findings about faculty and advisor relationships, some issues with disability services, and implications of the broader systemic influences on accessibility. We also limited our report to issues that emerged across, but not necessarily unique to, blind and low vision and DHH students, and we recognize that both groups may have distinctly different experiences. We hope to report on those differences in a subsequent manuscript.

[4]https://interactions.acm.org/blog/view/a-challenging-response

7 CONCLUSION

Our findings suggest that inaccessibility for graduate students is not effectively addressed with current technologies or institutional support systems, and that blind, low vision, deaf and hard of hearing doctoral students in computing operate at a deficit of support. They combined resources persistently to make up for this deficit, taking on responsibility that exceeds typical graduate school expectations to continue to make progress. We defined *access differential* as the gap between the access that nondisabled and participant students experienced; and *inequitable access* as the inadequacy of existing accommodations to sufficiently address inaccessibility. We outlined how participants experienced inaccessibility in graduate coursework and in conducting doctoral level research, showing how participants instituted workarounds and managed the many ways that graduate school is not accessible. This work illustrates the complex challenges that blind, low vision and DHH doctoral students in computing and related fields experience in striving to succeed in the highest levels of academia.

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