Usability, Accessibility and Social Entanglements in Advanced Tool Use by Vision Impaired Graduate Students

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Despite increasing work investigating the accessibility of research tools, most accessibility research has traditionally focused on popular, mainstream, or web technologies. We investigated barriers and workarounds blind and low vision doctoral students in computing-intensive disciplines experienced and engaged, respectively, when using advanced technical tools for research tasks. We conducted an observation and interview study with eight current and former Ph.D. students, closely analyzing the accessibility of specific tasks. Our findings contextualize how inaccessible tools complicate research tasks, adding time and effort, and exacerbating social entanglements in collaborative relationships. This work contributes empirical data that extricates how in/accessibility of advanced technical tools used in research influences productivity and collegial efforts.

CCS Concepts: • **Human-centered computing → Accessibility**; **Empirical studies in accessibility**; **Empirical studies in collaborative and social computing**; • **Social and professional topics → Computing education**.

Additional Key Words and Phrases: Higher Education, Workflows, Accessibility, Technical Tools

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1 INTRODUCTION

Graduate students with disabilities experience inaccessibility as a disparity between how they use and manage technologies and services and how nondisabled students use and manage those same technologies and services [22, 26, 44]. Often, despite systems and resources in place to provide accommodations to address access issues [50], access remains inequitable when solutions require overhead or are inadequate [14, 43]. Access inequity was defined as the degree to which accommodation addresses (or does not address) accessibility needs, especially leading to altered performance or slow progress when imbalanced accommodations make more work for students [43]. Indeed, less than 6% of doctoral recipients in computing reported they had a disability in 2017[1], indicating that few graduate students identify as blind or low vision. We may infer from this

[1]https://ncses.nsf.gov/pubs/nsf19304/data

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low rate that vision impaired students encounter substantial barriers to graduate research at the doctoral level that prevents advancement. Prior work showed that technical tools are frequently inaccessible [3, 5, 14, 44], but less is known about how blind and low vision students at the graduate level use *advanced* computing tools in their research. Although past research uncovered technical accessibility issues broadly, it is not quite known how inaccessibility at a graduate level of complexity may lead to barriers that stymie students' research progress.

For the purposes of our study, we define advanced tools by the nature of the tasks for which they are employed (*i.e.*, research tasks such as data analysis or academic writing), and by the level of domain knowledge and technical expertise that is required to operate them. These tools may include statistics and visualization tools (*e.g.*, MATLAB, R), tools for programming such as Interactive Development Environments (IDEs) and programming languages (*e.g.*, Eclipse, PyCharm, Java, Python), tools for data collection and analysis (*e.g.*, Zoom, audio recorders, spreadsheets), and tools for reading and writing (*e.g.*, Word, LaTeX, Overleaf, Google Docs). We also take into account that such advanced tools have been characterized as *feature-rich* [25], and their discoverability of features shown to be problematic [36]. Few studies focused in-depth on accessibility of advanced tools beyond programming [3, 5], writing [14], or the accessibility of tools for undergraduate students (*e.g.*, tools used in classrooms) [11, 13, 24].

In this project, we employed an interview and observation study to investigate how blind and low vision graduate students endeavored to work around technical inaccessibility, managed collaborators, and applied solutions when using advanced technical tools. Our findings document the degree to which complex tasks associated with advanced tools are impacted by inaccessibility. We present empirical evidence that disentangles tool inaccessibility, applied workarounds, and access-driven solutions, and that contextualizes influence on, and influence of, human involvement and collaboration. We offer a critical view of the implications of these access inequities [43] for advancing graduate students with disabilities [42]. Our findings explore instances of inequity, for example, by showing how many more steps a participant took to complete a task (Figures 1 and 2), or by documenting the effort involved in working around inaccessible tools/tasks (*e.g.*, engaging human assistants or managing collaborations). Findings from this study may enable future researchers and technology designers to target specific use cases and technical breakdowns toward solutions. This work contributes: (1) a focus specifically on complex interventions implemented by vision impaired graduate students when using advanced technical tools, and (2) empirical data contextualizing the state of accessibility of advanced technical tools used in research by vision impaired graduate students.

2 RELATED WORK

In this section, we present prior work on experiences of disabled graduate students and accessibility and usability of advanced tools commonly used in research.

2.1 Graduate Students with Disabilities and Critical Views on Higher Education

Most prior research investigating accessibility issues for students with disabilities in higher education focused on undergraduate students [11, 13], even though graduate level education and activities differ significantly from those of undergraduate students [22] particularly with regard to work ethic and individual well-being. For example, in a study about students with learning disabilities, Montoya et al. found that the academic, social, and emotional demands, and need for support of graduate students exceeded those of undergraduate students [30]. Others found that Ph.D. students received insufficient and ineffective support due to lack of accommodations for graduate-specific activities [22, 43, 50]. Tamjeed et al. [50], in a study about disability services for disabled graduate students, showed that campus disability services offices staff identified as assistive technology generalists and, as such, essentially lacked knowledge about the accessibility of technologies students used, or about technical tools for accommodation. As a result, disability services staff avoided providing technical support and instead they encouraged students to seek help from other students [50]. Other research showed that inefficient systems and procedures, and lack of support for graduate-specific activities drive graduate students to use ad-hoc strategies, such as seeking help from friends [22, 25, 43].

In addition to investigating accessibility and support for graduate students, recent work examined disabled experiences through the lens of ableism, or the situation when people without disabilities are elevated or privileged above those with disabilities [20, 43, 44]. Such work engages a critical angle [15] on the implications of structural power on student academic success, in particular the policies, social expectation, and physical environments in place that embed barriers to access [16]. Scholars working in disability studies have recognized the importance of focusing on access rather than the individual [53], drawing attention away from the effort to *cure* disability and toward social remedies for lack of access [53]. Therefore, we have concerned ourselves with access to tools, rather than dwelling on the details of disability to the problem of access, while recognizing "the limitations of technological interventions in a neoliberal political economy" [53]. Essentially, a critical view on students' experiences in higher education requires contextualizing how the social and physical apparatus that is academia sustains inequities that result in inadequate support for disabled students [19]. With this perspective in mind, and building on prior HCI and accessibility research with similar perspectives [43, 44, 54, 55], we consider the relationships to student autonomy and power manifested through tool inaccessibility.

2.2 Accessibility of Research Tools

Previous work with disabled graduate students explored inaccessibility in graduate school settings and what workaround strategies students employed to solve accommodation issues [22, 26, 43, 44]. Such work found technical tools or apps were not accessible to students, and broadly, laid bare how complexities in technical inaccessibility were associated with the advanced nature of the tools used, and the students' unique position as graduate researchers.

By contrast, other research focused on specific tools or tasks, for example, increasingly popular collaborative writing tools, such as Google Docs, Microsoft Word, and Overleaf (formerly ShareLaTeX), tout useful features like synchronous editing, commenting, tracking changes, or revision histories, etc. These tools were found to have significant challenges for screen reader users [12, 14, 41], specifically in that it was difficult for users to understand the context of comments and revisions, and to resolve comments [41]. To understand these issues further, Das et al. [14] conducted an observation and interview study with vision impaired academics and professionals about how they used collaborative writing tools with sighted peers, finding that people with vision impairments employed various interconnected processes in collaborative writing activities. Vision impaired users bore the burden of learning an ecosystem of (in)accessible tools and adapting to complexities of collaborative features in writing tools [14]. Though not specifically focused only on tools, Mack et al. more recently investigated how accessibility may be adjusted for user research methods, stressing the importance of emphasizing access needs throughout the entire user research process [27].

Observation-based programming studies found that blind and low vision developers regularly struggled with navigating IDEs to perform typical programming activities [3]. Often IDEs convey various information through visual analogies such as indentations to indicate code levels, different colors to represent different parts of syntax. Despite several efforts to make the visual structure of source code accessible [5, 37, 45], these types of visual information are still difficult to navigate and are not accessible with screen readers [47]. Meanwhile, vision impaired programmers rely on sighted colleagues to manage large amounts of information when on the job [28]. As a result, programmers preferred to use simple code editors such as Notepad and Notepad++ to write software more comfortably [2].

Most prior research focused on coding, pre-defined tasks (*i.e.*, reading email), or investigated how professionals work [3, 49]. Meanwhile, we endeavor to examine accessibility issues of tools used specifically for research by graduate students, which may include different approaches to coding, such as for data analysis (*e.g.*, R). We focused on tasks students already were conducting in service of their research objectives, in favor of ecological validity of the type and context of the issues encountered.

2.3 Accessibility and Usability

Usability is a component of user experience that captures how easy or difficult it is to perform tasks when using technology. A seminal paper exploring the difference between accessibility and usability by Petrie and Kheir, 2007 [35], cites the common definition of usability provided by ISO 9241: "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." They then propose to adapt this definition to accessibility, saying that accessibility is "*the extent to which a product/website can be used by specified users with specified disabilities to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*" [35]. Prior work studied accessibility and usability challenges for vision impaired users when interacting with websites [8, 36, 52], with screen readers [36, 52], with command line interfaces [40], and with both programming and non-programming tools [21, 33]. In a study on how blind users completed tasks on the web, Bigham et al [8]. described that "not knowing what you don't know" causes frustration and wastes time for vision impaired users because they do not know whether a feature is inaccessible or the content is not available [8]. Polturi et al [36] found that inconsistent information provided to screen readers was a major barrier to blind and low vision technology users [36]. These findings suggest that underlying system usability has implications for accessibility, *e.g.*, missing or inconsistent information may not be conveyed accordingly through screen readers, if at all.

Heuristic evaluation, one (albeit limited) way of assessing product usability, was developed by Nielsen and Molich [32], then refined by Nielsen [31] as a quick way to determine a technical product's usability. The ten heuristics still in use today are: *visibility of system status*, *match between the system and the real world*, *user control and freedom*, *consistency and standards*, *error prevention*, *recognition rather than recall*, *flexibility and efficiency of use*, *aesthetic and minimalist design*, *help users recognize, diagnose, and recover from errors*, and *help and documentation*. The heuristics are typically used by experts to evaluate products / designs during walkthroughs. Usability heuristics encapsulate usability concepts for evaluation and improvement, *e.g.*, identifying visibility of system status could indicate that signifiers are needed to improve communicating to users what is happening with the application.

Accessibility conformance does not necessarily translate into good user experience and usability. In fact, prior work examining the interplay between accessibility and usability reported that both concepts are closely related, suggesting an overlap between usability and accessibility [1, 4, 23, 35, 38, 39]. Bai et al.'s [4] survey study examined if e-government website accessibility increased usability for users without disabilities, finding that accessibility was a significant predictor of perceived usability [4]. Other research investigated the intersection of usability and accessibility issues, finding that nearly 15% of the problems identified were common for both sighted and blind users [35], and that 32% of web accessibility assessments were identified by users with and without disabilities [39]. Further research found a strong relationship between user experience attributes (*e.g.*, interest, disappointment, frustration, annoyance) and perceived accessibility [1]. By contrast, fewer usability problems were found to intersect with items covered in WCAG 2.0 [1, 38]. Much of this research suggests an overlap between accessibility and usability, yet is limited in understanding the role of technical in/accessibility nuances (*i.e.*, WCAG-specific guidance) on usability.

3 METHOD

Our approach was inspired by methods used by Szpiro et al. [49] and Albusays et al. [3] who conducted research drawing on contextual inquiry and qualitative data analysis. Szpiro et al. interviewed and observed people with low vision to understand how they access computing devices when performing simple tasks. Albusays et al. conducted online interviews and observations with blind developers to understand their code navigation challenges. Drawing on their methods, we used semi-structured interviews and observations of research related tasks to understand accessibility challenges of research tools, and to contextualize workarounds students employed to solve accessibility issues. Using this approach, we sought to gain deep insights via direct observation of participants performing tasks, and to gather first hand perspectives of advanced tool inaccessibility.

3.1 Participants

We recruited blind and low vision participants who were currently or recently (within the last 10 years) Ph.D. students in computing or STEM related fields. We recruited participants from a previous study in which the participants agreed to be contacted for future studies. In particular, we had a bit of knowledge about the participants' advanced tool use from the prvious study. We sent direct recruitment messages to 10 individuals, and eight responded and participated in this study. We compensated participants with $30 for their time. Six participants self-identified as blind and two as low vision. Three participants had graduated from U.S. institutions, one had left their Ph.D. program, and four were current Ph.D. students at different universities across the United States. Current and ex-students had completed at least two years of graduate study. We show an overview of the participant information in Table 1[2].

3.2 Interviews and Observations

With IRB approval, we conducted interview and observation sessions virtually via Zoom. All the study sessions were video recorded. The sessions lasted from 45 minutes to 2 hours and 15 minutes and occurred May through July 2021. Sessions averaged approximatey 1.5 hours. For most participants, we met over one session, however, for some participants we met over several days and several sessions to accommodate their schedules. The sessions included semi-structured interviews together with observations of tasks demonstrated by the participants. Since one of our goals was to understand how Ph.D. students use research tools, we did not pre-specify a list of tools and a list of tasks for observation. Rather, using Technology Biographies [9], we first asked participants about the top 3 to 5 tools they frequently used in their research. Together with the participants we decided on a tool on which to focus. Then we asked them to demonstrate tasks of their choice, asking for tasks they may commonly conduct for research using the selected tools discussed. We list the frequently used tools along with the tasks demonstrated or described by the participants in Table 1.

Following Technology Biographies allowed us to elicit rich and holistic insights from each session [9]. As such, our interview questions and observation prompts were structured in the following three categories:

Past & Personal History: We structured our questions about participants' *personal history* with the tools and their *first-time use* of the tools. For example, after asking their top tools and deciding

[2]To protect participants' identities, we remain intentionally vague about their specific fields of study.

Table 1. Participant information

PID	Vision	Field	Frequently used tools	Tasks demoed/ described
P1	Blind	Computer Science	Google Docs, LaTeX, BibTeX	Writing dissertation
P2	Low vision	Computational Science	Cygwin terminal, SSH, R, Python	Exploring data using R and Cygwin
P3	Blind	Computer Science	Screen readers (VoiceOver, TalkBack, NVDA, Windows Narrator, JAWS), DOS, Braille Display, Phone, Bone Conduction Headphones	[Described processes broadly]
P4	Low vision	Computing	Word, Adobe Acrobat PDF reader, PowerPoint, Zotero	Reading comments in MS Word; Adding citations in MS Word using Zotero
P5	Blind	Information Systems	iPhone, Zoom, Skype, Recording apps (e.g., Voice Memo), Word, Excel, KNFB, Online PDF to text converters	Conducting interviews
P6	Blind	Computational Science	R Studio, Word, Pages, Numbers, Excel	Understanding and manipulating molecular structures
P7	Blind	Computational Science	R Studio, Word, Pages, Numbers, Excel	[Described processes broadly]
P8	Blind	Computing	Word, Google Docs, Rev.ai, Recorder (Zoom, Portable audio recorder), Spreadsheets	Using spreadsheets for qualitative coding

with the participants which technology to focus on, we asked questions such as: What is your personal history of using the tool? When did you first use this tool? How was your experience when you first used the tool? Why did you decide to use this tool?

Present & Technology Tour: We focused questions about participants' *current use* and *last-time use* of the tools, including concerns and problems they faced using the tools. We started with asking open-ended questions such as: What are you currently using the technology for? Tell me about why this tool is necessary for your research? How did you use the technology the last time you used it? What was the task?

As a part of the technology tour, we asked participants to provide us an in-depth description and demonstration (when feasible) of a task using the tool. During the task demonstration, we asked participants to share their screen, and to relay their screenreader audio output through Zoom so we could record and observe the usage and performance of screenreaders alongside visual observations of task performance. While we observed participants performing tasks, we occasionally asked questions for clarification, for example, why they clicked on a button or why they navigated through menus again. Our focus during observations was to gain clarity about specific instances of interactions that were inaccessible, unusable, or that represented workarounds for such issues. We recorded the steps they took to complete the tasks and present two of them in diagrams in the Findings section.

Future & Guided Speculation: We asked participants to reflect in a *guided speculation* about *future developments and wishes*. We focused on gathering participants' perspectives about possible future improvement of the tools, and asked questions such as: What should happen in the future to this technology to improve it for what you need it for?

Neither P3 nor P7 demonstrated tool use, though they were interviewed. P3 did not have infrastructure in place to demonstrate technical tools, while P7 required sighted assistance for a demonstration, which was not available during the interview.

3.3 Data Analysis

We video-recorded the sessions and transcribed all the recordings. For data analysis, we followed a qualitative approach and focused on deep analysis of the tasks demonstrated and described by the participants. Initially, three researchers split three of the interview transcripts, observed tasks that participants demoed during these sessions, and noted their observations of the tasks in the transcript documents. Then, following an inductive open-coding approach [29], the three researchers coded the three transcripts including their observation notes individually, followed by discussions and aligning codes. One researcher continued writing observation notes and coded the remaining interview transcripts, they then discussed their notes with other researchers through weekly meetings. This initial coding pass allowed us to identify the tasks for further in-depth analysis as it helped in understanding how much information each task provided and what we learned from each task. We also sought to have broad coverage, so we wanted as many different tasks as possible, but not necessarily similar tasks across different participants.

After choosing the tasks for further analysis, one researcher wrote detailed descriptions of the selected tasks in separate documents capturing every step that the participants took in completing the tasks, adhering to practices of "thick description" as much as possible [17, 46]. This process required going back to the video recordings to document visual observations (*e.g.*, when popup windows blocked the document being demoed), as often steps taken by participants were not clear from only the transcript. In another pass, the task descriptions were edited for clarity and accuracy according to the video recordings, and finalized for further discussion and reflection. The researchers reviewed and vetted the task descriptions for key accessibility issues, then they discussed the descriptions extensively to address potential issues of bias as much as possible. After these discussions, the researchers individually wrote reflective memos for each task, closely examining accessibility issues, before coming together to discuss again as a group. Finally, the researchers reflected on the tasks as a group toward refining the accessibility issues included in the findings section. This process was completed over a period of 3 months and the discussions were conducted through weekly meetings.

Our analysis was informed by Grounded Theory as initiated by [18], refined by Corbin and Strauss [48], and by qualitative analysis as outlined by Patton [34]. Per Glaser and Strauss, Corbin and Strauss, and Patton, we engaged semi and unstructured interview styles because though we framed interviews with Technology Biographies initially, we did not always know what tools would be demonstrated or discussed, and we included follow-ups according to tool/task. We checked our interpretations of the data with each other continuously, with subsequent interviews, and through triangulating demonstrations with descriptions and with other participant data where appropriate (*e.g.*, the various participants who copied text from an advanced tool to a text editor for further manipulation). Our collective comprehensive understanding of each phenomenon is bolstered by the richness of the data, the discussions we held, and by our previous interactions with participants.

4 FINDINGS

Our findings show how participants engaged in complex tasks. Specifically, we documented how they employed tools, and used workarounds and human assistance to manage research activities of a large scale: analyzing big datasets, managing substantial volumes of words, comments, and detail-oriented inquiries. We did not observe tool-use completed *without* an accessibility adjustment, additional tool, or workaround. The interactions we observed characteristically involved a main tool directly conscripted for the research task, *e.g.*, R, and an accompanying accommodation or workaround. Given the substantial scope of the activities, these additional tools or workarounds amounted to additional time and effort.

We organize our findings into two main themes (Table 2): (1) usability and accessibility, especially with using multiple tools and inadequate usability; and, (2) the role of human assistants in access problems and solutions, contextualizing where assistants functionally bridge access, and when they contributed or detracted from accessible solutions. Our findings contribute to the growing literature characterizing aspects of human assistance as an important component of accessibility [6, 7, 10, 43, 51], and consider how such assistance comprises access resolution, *collaboration and* access resolution, and *meeting social needs* in collaboration.

Table 2. Summary of Findings

Finding	*Example Research Activity*
Usability and Accessibility	
Multiple Tools	P2: used R, Cygwin, and text files to read stale terminal output
Usability Violations	P4: navigated Word and Zotero by memorizing commands for unlabeled buttons, encountered usability challenges when comments disappeared into a separate pane
Human Assistance and Access Problems	
Human Assistance as Functional Accessibility	P6: utilized sighted assistance to 3D print molecules for study
Collaboration Complicates Accessibility	P1: used Google Docs, text editors, and LaTeX to satisfy collaborator requests; P8: selected to use spreadsheets that met access needs, not necessarily collaborator needs

4.1 Usability and Accessibility

Participants' demonstrations of how they used tools to work through complex research tasks revealed how usability interweaved with accessibility.

4.1.1 ***Multiple Tools.*** Almost all participants reported using multiple tools (other tools used in addition to assistive technologies) to complete tasks that were typically meant to be completed with one tool. Reasons for using multiple tools included: inaccessibility of the main tool entirely, improved accessibility for specific tasks, routines and familiarity with older accessible tools, and lack of knowledge about improved or new tools with no time to learn new—possibly more accessible—tools.

We found familiarity with old tools and lack of knowledge about new tools was one reason P2 gave for their choice of tools used to analyze multidimensional genetics datasets. They used the R programming language with a Cygwin terminal to explore and analyze data, and to create plots and reports. However, R and Cygwin had some limitations which prevented full access to datasets, matrix rendering, or reports. P2 demonstrated how they used R and Cygwin interchangeably to execute several tasks (Figure 1), as we show in the brief excerpt from our observation notes below.

> *P2 opened the Cygwin terminal and created a matrix using an R command, which was subsequently read out loud by the screen reader. P2 pressed the up and down arrow keys showing the previous input commands that had been read aloud, but not the associated output. The output portion of the terminal showed the matrix P2 initially created. P2 used shortcut keys to open the terminal menu, and chose the "Edit > Select All" option, which selected the entire terminal content. P2 copied this content, opened a Notepad text file, and pasted the copied content into the text file. In the text file, they moved up and down between the lines and explained, "[now] I can tell what was my command [...] and what's the output."*

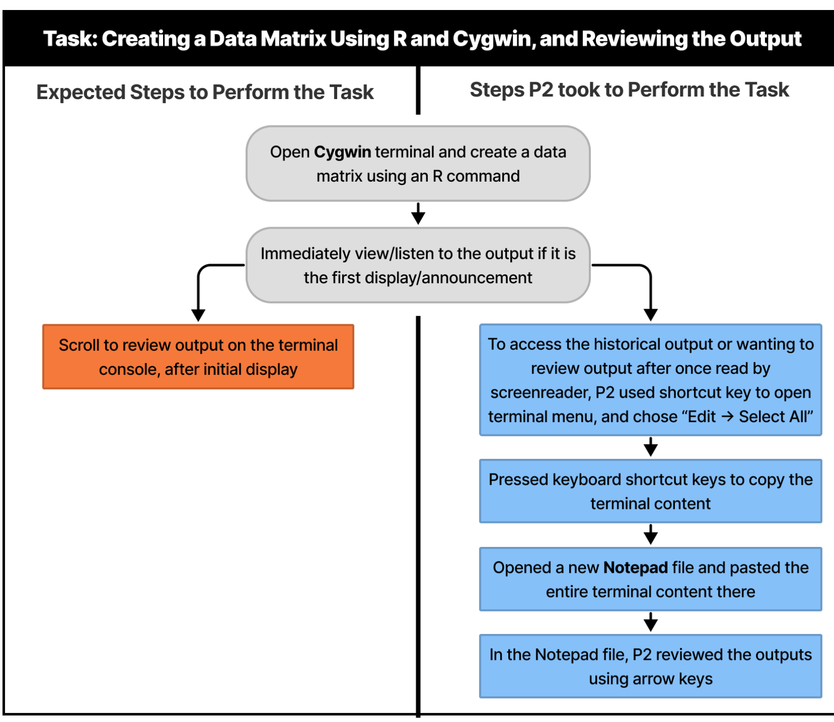

Fig. 1. Steps expected of a user to create a data matrix using R and Cygwin and reviewing the output are shown on left side of the diagram (non-workaround), and additional steps the participant took to complete the task are shown on the right side of the diagram (workaround)—rounded rectangles show shared steps and are positioned center in the diagram.

P2's demonstration illustrated several key interactive details: First, once terminal output is read by the screen reader, it cannot be accessed again, even though it is visually present. If P2 wanted to review results after several more commands, or go back to check on something in more detail, they had to rerun the command to refresh the output for the screen reader. Second, they incorporated a workaround to the rerun option using copy and paste with a separate text file. Third, a limitation of this workaround was that *all* the terminal output text would be copied over. Therefore, to access specific results, P2 had to recall what command they used for the output they wanted so that they could find it within the text file. For example, if P2 wanted to review the matrix they first created as described in our observation notes, they would have to recall the specific command they used, or something of the output, to locate the matrix.

Amongst the many ways that participants used multiple tools, we note several participants employed this kind of workaround: copying content from an advanced tool to a simpler one for analysis or manipulation, even if the tasks themselves were widely different. For example, as we show below, P1 moved text from Google Docs to a text document, P4 copied comments from Word to a text document to locate specific information, and P8 chose to move from .xls files to ".csv" files for easier navigation with their screen reader.

4.1.2 ***Usability Violations***. Multiple tools—in place of a single tool—risked usability issues, compounding vulnerabilities already present in usability issues of individual tools. We saw this issue when P4 demonstrated how they navigated Zotero and Word. P4 developed strategies to work around unlabeled buttons in both Word and Zotero, learning to recall tab order or to know when to use up and down arrow keys instead. We again excerpt our observations notes of their demonstration:

> *In the Zotero plugin from Word, the "Add/Edit Citation" window appeared and they typed an author name into the search field, then tabbed to the search result box, where they read through the search results one at a time. When the desired citation was located, they selected the citation by adding it to an unlabeled area box (this box enabled them to list multiple citations to add at once). They followed the same approach to add a second citation to the box. We observed that they tabbed through the buttons out of order to add citations. At this point, P4 indicated that the area box along with its associated arrow shaped buttons was not labeled (for screen readers). Visually, we observed that the buttons were arrow-shaped and did not have text on them. When all citations were selected, P4 navigated to and selected "OK" to insert them into the document.*

The need for P4 to memorize commands to make up for missing labels and inordered navigation challenged the tool's usability. P4 further explained:

> *"I remember that these buttons are not in the tab order, so I learned by accident [...] that if I use that control navigation feature of the NVDA I will get to these unlabeled buttons which the second one is the Add button" (P4)*

P4's comment elucidated how the usability concept of recognition over recall is violated through a combination of unlabeled buttons and out-of-order navigation. P4 recognized this issue of misalignment with how they conceived of how to use the application:

> *"I have never learned when it does this and when it does that. You know, this is not predictable. And unpredictability, I think, is the most harmful thing when we develop a mental model..." (P4)*

Despite managing to recall many steps throughout the process, the mismatch of their mental model via inconsistency, missing information, and navigation issues may become untenable.

Similarly, P4's experience highlighted how accessibility could be exacerbated by usability issues, and emphasized how multiple tools could be used to expand access. They demonstrated how difficult it was to access comments in Word with a screen reader when there was a lot of collaborator feedback, characteristic of dense academic documents at the graduate student level (Figure 2).

> *Using the NVDA screen reader, P4 opened a Word document with comments already in it. P4 went through each line in the main portion of the file, reading the document. We observed the screen reader said only "has comment," but did not state the name of*

the commenter each time it encountered text with a comment, despite commenter names visibly showing in the comment bubbles. Upon encountering a comment, P4 switched to JAWS, and using hot-keys, extracted the comments from the Word document, opened a Notepad text file, and pasted the comments with commenter names into it. The extracted comment in the Notepad file was not associated with the text content of the Word document, so P4 was unable to determine which text each comment was referring to. Upon finding a comment to reply to or resolve, they switched back to the Word document and used the search feature to find the original comment (using some text of the comment) and resolved or replied to the comment there.

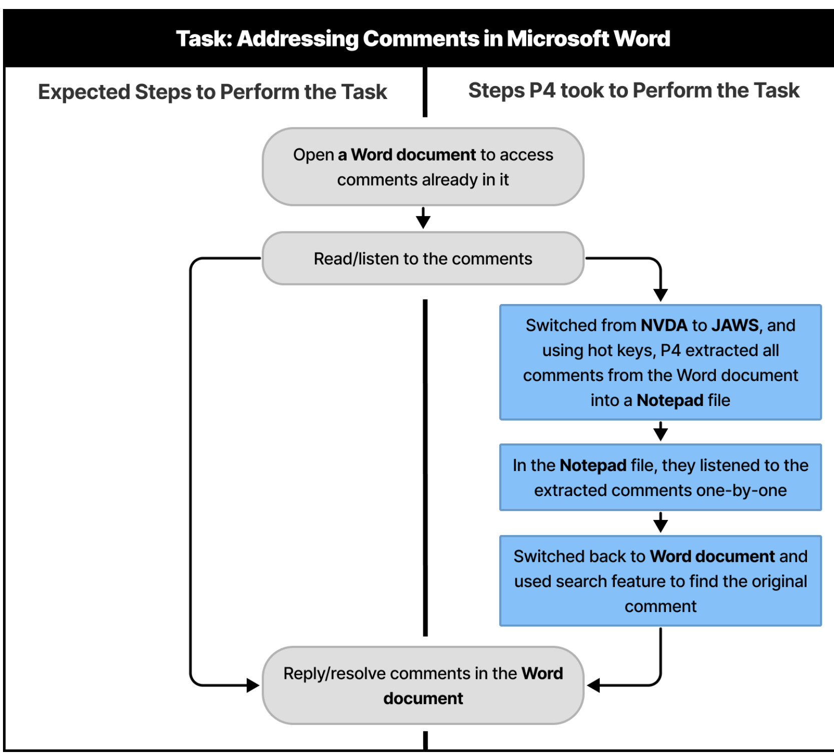

Fig. 2. Steps expected of a user to address comments in a Word document are shown on left side of the diagram (non-workaround), and additional steps the participant took to complete the task are shown on the right side of the diagram (workaround)—rounded rectangles show shared steps and are positioned center in the diagram.

P4 could not know both who commented and where at the same time. To resolve this issue, P4 "humbly" asked their collaborators to write their initials at the beginning of their comment text (*e.g.*, "[Initials]: do this"). The second issue was that the scale of comments exceeded the allowable commenting "bubbles." When a document had too many comments to fit the page margins MS Word automatically moved the comments to a separate REVISION pane, which was "totally inaccessible both with NVDA and JAWS." The abrupt change led P4 to resort to asking a sighted person for assistance to find the missing comments:

> *"I was so stressed because you know I had to respond to so many comments for the paper and I wanted to manage that because I was the first author... wanting to lead my team..." (P4)*

Together, they found the comments in the revision pane, though P4 did not know what triggered the move to the revision pane, *"that was a real mess because you don't know when it happens."*

These examples showed how usability issues arose: (1) working around inaccessibility by incorporating additional tools introduced multiple points of potential usability issues for P2 and P4. What if P2 could not recall specific commands when they searched the Notepad for a past result? How much trial and error had P4 undergone to ascertain when the tab key would hit the correct arrow button to select a citation? Also, (2) access to one tool does not necessarily mean access to other tools, such as plugins. P4 had sufficient access to Word, and minimally usable access to the functions in Zotero; they experienced difficulty trying to access the Zotero plugin on Word. In both examples, usability issues arose that risked the robustness of the process (P2's cut and copy method to read results in text files) and the accuracy of the task (P4's use of recall to facilitate the process to add citations). Finally, (3) P4's experience with comments was perhaps a case of not knowing what the problem is, or even that it exists [8], particularly brought on by a lack of knowledge about the system state, a key usability principle [31].

4.2 Human Assistance and Access Problems

We posit that all tasks participants shared with us have an element of social consideration / influence *and* tensions of usability and accessibility. Participants referenced the role of other people in process, tool selection, and accessibility problems and solutions. We identified examples of how human assistance or social expectations influenced accessibility outcomes.

4.2.1 ***Human Assistance as Functional Accessibility***. As a matter of fundamental access, human assistants are often called upon to provide support for visual access [6, 7, 10, 44]. In some cases, human assistants bridge functional inaccessibility, such as providing verbal descriptions of images that lack alt text. P6 shared how they employed human assistants in this functional way: to gain access to dimensions that were otherwise only available visually. P6 used proprietary software to study and manipulate molecular structures, usually represented in 3D images showing the positioning of different atoms alongside others in a molecule, spatially. Unfortunately, images in these proprietary tools were not accessible, nor did the tools provide relevant information about the different parts of the molecule in alternative formats (*e.g.*, text). This proprietary software did not work with screen readers, yet required visual inspection of graphical data displays for interpretation and analysis, as P6 explained:

> *"ChemDraw is also something I used very widely, but I use with an assistant because it was also inaccessible... [these packages are inaccessible] because they're drawing packages, [and] drawing is just not intuitive when you're blind." (P6)*

P6 enlisted help to gain access via verbal descriptions of the visual representations, using sighted assistance to bridge inaccessibility to the graphic renditions. These human assistants served no other purpose than to convey the information in an alternative format, *e.g.*, verbal description. Eventually, P6 developed a workaround so that they could better understand nuances of the visual representations that sighted assistants could not capture. However, even that approach still required sighted assistants to bridge access needs: P6 first converted strings of chemical structures to ".com" files where they entered edited specifications and code on calculations they wanted to execute. Next, working with a sighted assistant, P6 submitted the .com file for calculation with the 3D printer:

> *"I actually had a 3D printer that printed in ABS plastic, which I was able to run with some assistance. The technology to load [...] files in, orient them, and print them was not accessible, so I had to work around [with sighted] assistance." (P6)*

We separate out the kind of sighted assistance that P6 refers to, specifically utilized to gain access to the physical properties of the molecules (usually rendered graphically). Sighted assistants were hired for their ability to describe the visual output, and later, to operate the 3D printer. But the intellectual specifics of the molecules and associated parameters, P6 synthesized and managed, using what they called their "chemical intuition." P6 believed they would not have been able to do their work without sighted assistance, saying,

> *"I will be totally honest with you... a large part of my ability to study chemistry [...] was [through] the use of assistance." (P6)*

Meanwhile, the sighted assistant did not contribute to the intellectual aspect of the work, and so their relationship was not necessarily collaborative. Thus, P6's examples disentangle the analysis and computations required to do the *research* (their "chemical intuition") from the inaccessibility of the *tools* used to execute on those analyses and manipulations.

4.2.2 ***Collaboration Complicates Accessibility.*** Participants generally had a clear understanding for which tools were accessible to them, and as such, which tools they preferred to work with. Working with collaborators could complicate their choice of tools, if collaborators had specific preferences, requests, or systems. Participants accommodated collaborator preferences to varying degrees, often due to power imbalance, adjusting either the tools or the processes they used. Consequently, these adjustments could change the accessibility of the tool or process. In contrast to the paid assistance P6 used, human involvement for other participants included collaborative relationships. In these cases, as shown in related work [6, 10, 14], participants engaged with colleagues in research collaboration *and* they enlisted their help for access needs, as necessary. P1 described a workaround they used during the dissertation writing process to meet committee members' preferences. P1's preference for LaTeX, and their dissertation committee's desire for the web-based collaborative and auto-complete features of ShareLaTeX (now OverLeaf) contributed to tension in the writing process:

> *"[not using ShareLaTeX] was not awesome for them, because what they had to do was write LaTeX like I did. Just knowing the syntax and doing it, whereas in something like ShareLaTeX, it kind of does complete [it] for you." (P1)*

To satisfy the committee's collaborative preference, P1 agreed to write first on Google Docs (but in LaTeX syntax) and to process their own LaTeX source and rendered PDF. To adjust, P1 developed a process where they switched between Chromevox—a deprecated Google screen reader that is only available in Chrome—and VoiceOver. With writing finished, they used Chromevox to copy the Google Doc content before switching to VoiceOver and pasting the content into a text file. Next, using a text editor, P1 linked the dissertation chapter files and image files (previously saved with sighted assistance). To link all the dissertation chapters in the subfolders, P1 wrote an umbrella document using local text editors. Finally, P1 ran pdflatex in a terminal window with the dissertation folder as the current folder at least twice, then they ran BibTeX, then pdflatex once more, resulting in a pdf of the entire dissertation. In describing their experience, P1 added that they used two different local text editors, but that they were not always sure which text editor was selected by the file finder, sometimes leading to some usability issues.

P1 encountered two main issues in their process. First, like P2 and P4, P1 incorporated the use of text files to copy content from one tool to another. These additional steps introduced potential for error, *i.e.*, P1's tendency to sometimes select a second text file editor by accident.

Second, synchronous collaboration opportunities were limited to the first phase of writing, and subsequently unavailable when content was copied over to the text file to facilitate the LaTeX process. P1 did not discuss back and forth editing passes on Google Docs after they went through the pdflatex process. However, it is reasonable that changes may have occurred after content was copied (as researchers, we share a similar experience when we add accessibility using Adobe Acrobat, only to make changes in the source file that force the entire process again).

As a final example, we contrast P8's experiences using spreadsheets for data analysis while collaborating with colleagues. P8 explained that many qualitative coding tools are not accessible to screen readers, and the nature of their work involved independently coding data before sharing among colleagues. Therefore, unlike P1, P8 eschewed the collaborative aspect of their work, separating the need for digital access from the need to cooperate with others. Based on this decision, they selected Excel (a more accessible spreadsheet tool) instead of Google Sheets (even though it could be used collaboratively):

> *"I'm better at using spreadsheets for coding qualitative data... because I have more experience as a researcher, and I understand that...for that tool to work really well, I need to have everything, everything needs to be regimented." (P8)*

Thus, the ability to organize and navigate data accessibly was appealing and prioritized. Aside from compartmentalizing collaborative aspects of the work until after data analysis with the spreadsheets, P8 emphasized that the tool was essentially accessible, and therefore, useful to them:

> *"visual presentation doesn't really matter for me. And so like everything is divided into cells. Um, so whereas visually, you know, a cell [with] a lot of information, and a cell with a very small amount of information would look very different. If put side by side on the screen, they're all equal to me. And so I'm able to kind of move very quickly through columns and rows, and to get an idea." (P8)*

P8 navigated the spreadsheet using filters and sorting depending on the information they were seeking. They used page-down and page-up operations to skim many rows at once quickly, getting a quick sense of a row's contents before moving on. In some cases, the cells were empty and the screen reader said nothing, other times, P8 moved on before the screen reader was finished reading the cell's entire contents. P8 described issues in working with large datasets that might span many rows and columns, subsequently slowing down navigation:

> *"I would be 50 or 100 rows down, if I typed into a cell, or if I was moving from one cell to another, I would hear two or three seconds of silence before hearing my screen reader announce whatever was in that cell, or announce what I was typing. And that became really, really, really unwieldy, because you add that up over time and it just—I can't wait that long." (P8)*

As a result, they opted to save the spreadsheets in CSV format, "and they worked better." Despite these navigational strategies (sorting, using CSV format) and the benefit of being "regimented," P8 noted that it might be hard to find data if there are many cells that are empty:

> *"Sometimes I don't discover things. So, what I notice a lot of people will do is they'll have columns of data. And then they'll have some empty columns or empty rows. And then they'll have like another set of information, maybe their formulas or something like that. And sometimes discovering where those things are... I wish I had some ...high level 'this document has data in columns A through J, and then in columns P through R, and in rows whatever through whatever,' because I've missed...things [because]... I just don't know to continue searching. That is a challenge." (P8)*

Unlike P1, P8 separated the collaborative work from independent effort, making choices based on accessibility and usability (*e.g.*, choosing to use Excel in lieu of collaborative tools like Google Sheets), then meeting with collaborators for synchronous discussion. We note that despite this choice, P8 still encountered usability issues with Excel when datasets were large, driving a move to CSV files in such cases. P1 and P8's experiences highlight the tradeoffs when entangling work with advanced tools and collaboration. Acquiescing to sighted colleagues' desire for synchronous editing introduced significantly more tasks for P1; meanwhile, it motivated P8 to work through a different path altogether. Given P1's resulting process and P8's measured consideration, we conclude that if not considered carefully, complying with collaborators may risk inviting accessibility issues.

5 DISCUSSION

Our analysis showed how accessible solutions involving advanced technical tools could exacerbate existing or create new usability problems, and how poor usability in itself contributed to accessibility issues. We further clarify human assistance in terms of functional access, and collaboration in terms of how it may have risked making tools and processes inaccessible, complementing prior work on nuances in mixed-ability collaborations and the care work of access [6, 7, 10, 26, 51].

5.1 Accessibility and Usability

Our findings showed that access accommodations operate (or do not operate) alongside equally important usability issues. Several of our participants opted to use multiple tools in addition to the main analytic or writing tool (*e.g.*, P1, P2, P4). In doing so, they often switched between screen readers, adding another set of tools to their growing cache. Further, it is not clear that there are specific patterns for the various approaches, even though we saw several instances of similar strategies. For example, many involved copying text from a main technical tool (R, Google Docs) to a simple text file for review or manipulation, while at the same time, mechanisms for doing so varied: they may or may not switch screen readers, and even if they did that was not consistent: some switched between NVDA and JAWS, or between Chromevox and VoiceOver. These practices were derived to address access hazards (Chromevox provided better access than VoiceOver in Google, switching to JAWS gained access to comments in the revision panel in Word), but also introduced usability risks (switching between applications introduces errors, like selecting the wrong text editor).

Our findings also revealed some limits of accessibility and usability in systems used. P6's technical systems were almost completely inaccessible to them, such that human assistance was necessary. Meanwhile, P1, P4, and P8 used mainstream tools (Google Docs, Word, Excel, etc.) or more commonly used research tools (Zotero, LaTeX) with screen readers to a reasonable degree, yet hit a usability ceiling with large datasets, a substantial number of comments, or lengthy outputs (*i.e.*, searching an entire console history in a textfile, or not knowing that comments have moved). These cases show that accessibility may have deteriorated due to usability issues [1, 4, 23].

Interestingly, participants admitted there could be relatively newer versions of tools available that might have had better accessibility (P2 mentioned a new version of Cygwin might be improved), but they did not have time to explore or learn new tools. P1 insisted on using a deprecated tool (Chromevox) because it was familiar, easy for P1 to use, and the best tool for their tasks with Chrome. Contrastingly, P8 strategically opted out of tools that were not accessible to them, and selected more accessible tools depending on the independent or collaborative aspects of the task. Although P8 prioritized their tool selection on accessibility, the choices of most participants reflected the complicated nature of their work, their work habits, and the tension between usability (*i.e.*, familiarity of tools) [35], and expectation (*i.e.*, producing research results in a timely fashion) [44].

We recommend that in addition to considering task ecosystem in tool development (auxiliary tools, or adaptive or enhancements such as screen readers or other text editors) [33], the usability and accessibility of coupled technologies must be emphsaized. Accessible tools and functions may presume usability of the underlying system, which could lead to accessibility issues if usability is poor. Future study could include in-depth analysis of the interplay between accessibility and usability toward definitive guidelines. Additionally, accessibility tools and solutions should include testing requirements with extreme test cases: larger datasets, more collaborators in a single document, longer documents, etc. Evaluation of robust extreme test cases could expose accessibility issues that arise in such cases. Further, more attention should be paid to transitions from older and deprecated tools to new ones, particularly focused on maintaining usability across versions.

5.2 Human Assistance and Collaboration Complicate Accessibility

Our findings showed that some human assistance is a substantial mechanism for access, *i.e.*, P6's paid sighted assistants conveyed visual information that was not accessible to them but did not necessarily otherwise contribute intellectually to the work. An interdependent framing emphasizes the clear access needs that P6 described while also acknowledging their scholarly contribution to the work (*e.g.*, "Interdependence can reveal the work done by people with disabilities") [6]. In contrast, we recognize that human involvement entangled in social relationships may also be an essential aspect of interdependence [6] and productivity [10], and can be incorporated with empathy [7]. Revisiting social expectations might help alleviate constraints, and access requests may often have implications for norms and attitudes [14, 21, 26, 51].

We consider that when entangled in social dynamics, particularly involving expectations and perceptions, accessible solutions inhabit a "solved" state if some accommodation is in place, regardless of the actual quality of that solution. P1's practice of using Google Docs, then text files, then LaTeX to generate PDFs introduced an entirely new set of steps to the writing process. Although P1 reasoned that it might have been easier if the preferred tool, ShareLaTeX, were accessible, or if collaborators were more comfortable with LaTeX, P1's approach to resolving the issue was to acquiesce to collaborators. Managing these social dynamics is fraught particularly within power structures [19], where senior colleagues may eventually make decisions that could impact the junior researcher's success [10, 26, 43]. Understanding that relationships between disabled students and nondisabled superiors are tricky [19, 44], we can infer that P1 aspired to maintain professionalism and to reduce collaborative tension [26, 51].

Further scrutinizing the social dynamics at play, we consider that P1's solution—collaborate in Google Docs and process LaTeX offline—may have sufficiently reconciled collaborative access issues for *collaborators* while obligating P1 to a sometimes unwieldy and time consuming workaround. Participants reported on how work was completed after the fact, thus we infer from P1 that collaborators may have thought accessibility issues resolved because Google Docs was accessible (compared with ShareLaTeX), while in contrast, P1 continued to work through a convoluted process as part of the "solution." In particular, a resolution is implied because it was P1's own suggestion to use Google Docs and apply the resulting workaround. Though P1 did not explicitly communicate that their collaborators thought any accessibility issues resolved, that they proceeded with the resulting steps suggests that their solution placated collaborators' preferences. A critical view on this solution shows the potential issues of power at play [15, 19, 42]. The additional effort may have been acceptable to P1, as they seemed at ease working with LaTeX. But, the inequality of the additional steps that only they, a vision impaired student, would take makes clear the impact on their efficiency and productivity [26, 43]. Thus, when participants proposed a workaround (such as in P1's case), or agreed to a solution (when P4 asked colleagues to write their initials in the comments) that was then carried out, it may have been that sighted colleagues assumed the accessibility issue was thereafter covered and no longer a problem.

Finally, we note that P4's experience with commenters was suggestive of the implications of social dynamics and quick fixes: asking collaborators to include their initials in the comments could eliminate the workaround of copying over comments to a text file. This experience echoed findings of "transactional" adaptations from Das et al. [14], but as P4 admitted it was challenging to decide to ask for the accommodation given the seniority of the collaborators, it also highlighted how such functional transactions can be embedded within power dynamics [19, 26, 44]. Further, adding initials quickly addresses the access issue of not knowing who made a comment, but it does not address the underlying accessibility issue: lack of access to commenters' names remains a problem. For this solution to be effective, P4 and their collaborators would have to continue to maintain the practice of including initials in comments. Although such a practice is likely not an issue, what would happen when P4 interacts with new colleagues? At each new collaboration, they are presented with the same access issue, must take into consideration the social dynamics, and pose an ask for the accommodation. Continually reasserting accommodating norms may be challenging, awkward, and exhausting [26] and constantly positions the asker, the student with a disability, at a disadvantaged position, at the mercy of the collaborator's agreement [19]. These considerations underscore the need for a full solution to the accessibility problem.

We recommend future investigations on these social dynamics, particularly as they relate to collaborative work in accessible environments and have implications for interpersonal relationships. Prior work shows that such considerations require nuance [6, 14, 21, 26, 51]; here we offer a distinction especially for humans only in access resolution (*e.g.*, P6's 3D printed models) as contrasted with collaborative relationships that may potentially exacerbate access problems.

6 LIMITATIONS

We interviewed and observed participants from a small population of people with disabilities with advanced degrees (or who are pursuing advanced degrees). We also did not apply a full thematic approach to our analysis, instead choosing to focus closely on individual choices and actions within a task, and reflecting on how choices were made and what consequences arose. Our analysis was focused on specific examples and is not meant to be representative of vision impaired graduate students as a whole. Therefore, we are unable to make general claims about using tools broadly, although we provide detailed examples to aid in comparisons. We are unable to report on comprehensive social dynamics that may be at play across different tasks that we observed and report on, and so we refrain from doing so.

One limitation of this study is that we do not have firsthand perspectives from sighted colleagues to definitively know if collaborators thought that access issues were resolved with workarounds. We expect some degree of nuanced understanding between participants and sighted colleagues, particularly if they were longtime or close collaborators. However, given the nature of our discussions with participants, particularly the final-state description of the tasks (*e.g.*, participants described what was actually done, after accommodations and decisions about tools and processes were made), we can reasonably expect that participants and their collaborators had settled on tasks, workarounds, and accommodations as described to us. From these descriptions, we can reasonably infer that collaborators accepted the tools and systems used were accessible and usable to participants.

Finally, we acknowledge that different user experiences for each participant, and varying accessibility of the tools they used could have influenced individual situations as reported. Our findings show that issues were severe enough to arise, despite these possible variations. Future work could investigate the impact of past experiences with vision (*i.e.*, if participants had lost vision or were congenitally blind), past user experiences with different tools, and the legacy vs. new tool status.

7 CONCLUSION

We conducted observations and interviews with eight blind and low vision current and former Ph.D. students in computing fields to understand how they used advanced tools in research. We closely examined workarounds and alternative tools that student researchers employed to solve accessibility issues. We critically analyzed tasks participants demonstrated or described and shared exemplars of tool use alongside our analytic reflections. Through specific examples we showed human roles in access resolution and in collaboration. We also showed multiple tools—a common solution for accessibility issues—introduced additional accessibility issues, and that usability-related issues added to accessibility issues and vice versa. We contribute empirical evidence and analysis on specific instances of inaccessibility and access resolution, which may be used to inform future directions for work: deeper consideration for the relationship between usability and accessibility, better incorporation of extreme use cases to support advanced technical work, and we offer a framing of human assistance with regard to access resolution, to complement the growing literature on interdependence and social dynamics in accessibility.

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