

Understanding Blind Screen-Reader Users' Experiences of Digital Artboards

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ABSTRACT

Two-dimensional canvases are the core components of many digital productivity and creativity tools, with “artboards” containing objects rather than pixels. Unfortunately, the contents of artboards remain largely inaccessible to blind users relying on screen-readers, but the precise problems are not well understood. This study sought to understand how blind screen-reader users interact with artboards. Specifically, we conducted contextual interviews, observations, and task-based usability studies with 15 blind participants to understand their experiences of artboards found in Microsoft PowerPoint, Apple Keynote, and Google Slides. Participants expressed that the inaccessibility of these artboards contributes to significant educational and professional barriers. We found that the key problems faced were: (1) high cognitive loads from a lack of feedback about artboard contents and object state; (2) difficulty determining relationships among artboard objects; and (3) constant uncertainty about whether object manipulations were successful. We offer design remedies that improve feedback for object state, relationships, and manipulations.

CCS CONCEPTS

• **Human Centered Computing** → **Accessibility technologies**; *Empirical studies in accessibility*; • **Social and professional topics** → People with disabilities.

KEYWORDS

Computers and creativity, creativity applications, art and design programs, accessibility, usability, blind and low-vision users.

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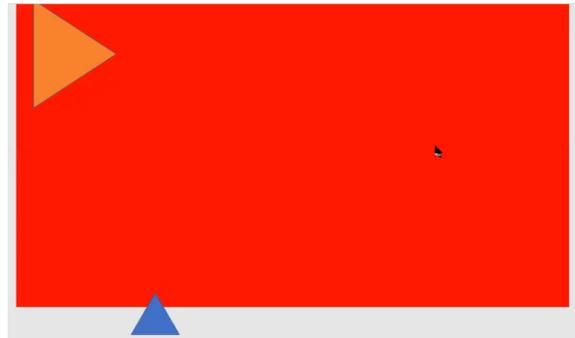


Figure 1: An artboard's state after a participant attempted to change the color of the triangle in the top-left corner to red. The participant's screen reader switched focus off the triangle, and she turned the canvas red instead, but was unsure whether any color changes had occurred.

1 INTRODUCTION

Creative and professional software applications involving 2-D digital canvases like Microsoft PowerPoint, Apple Keynote, and Google Slides are prevalent in schools and offices around the world; familiarity with such applications an expectation of many employers. Blind software users, however, are often confronted with significant accessibility barriers when using screen readers to interact with applications containing 2-D digital canvases producing heavily visual—as opposed to textual—output. Although screen readers can announce some visual data for blind users, the information offered is often either incomplete or difficult to interpret. The current state-of-the-art design solution is to add ALT text labels to canvas objects, but these labels are often not provided or are insufficiently descriptive. ALT text is also unavailable when blind screen-reader users are the creators, rather than the consumers, of a canvas project. In short, blind screen-reader users who wish to access a 2-D canvas, whether as a consumer or as an author, are generally unable to do so with current technology.

We have identified two broad categories of 2-D digital canvases: the object-based canvas, which we will refer to as an “artboard,” and the pixel-based canvas, which often supports a “paint canvas” metaphor. Artboards maintain object integrity as users manipulate shapes, images, and text; examples include digital presentation programs like Microsoft PowerPoint, web content like the HTML5 <canvas> tag, and vector-based drawing and editing programs like Adobe Illustrator. Pixel-based canvases, on the other hand, only

retain information at the pixel level, which allows for finer-grained manipulations but does not maintain object integrity; examples include image editors like Adobe Photoshop and drawing programs like Microsoft Paint. As digital presentation tools are used regularly in work and school, our study focuses on artboards, in particular the digital presentation tools familiar to our participants: Microsoft PowerPoint, Apple Keynote, and Google Slides.

Research to date has focused on devising drawing programs for blind creators [11, 22, 27, 31], as well as into alternative modalities of communicating visual information [16, 18, 26, 35, 39, 45, 56]. Several of these solutions [20, 31, 35, 53, 54, 57] necessitate special hardware or assistive technology. Additionally, others are focused on highly-specific types of visual information, such as graphs [16, 30, 45] and maps [18, 26], which may or may not be generalizable to artboard programs. As a result, there is no general-purpose software-based solution to support blind users in accessing 2-D digital canvases that can be deployed at scale with off-the-shelf technology.

To understand the needs of and issues faced by blind users of artboards, we conducted a mixed methods study in two phases: (1) We conducted 12 contextual interviews of blind users while they used their screen readers with digital artboard programs, namely presentation software, and (2) using task-based usability tests, we evaluated the accessibility and usability of two popular artboard programs, Microsoft PowerPoint and Google Slides, with 12 blind users, 9 of whom participated in the contextual interviews. We took our data from both phases and analyzed it using thematic analysis [13] and descriptive statistics, extracting key themes that characterize our users' experiences and sentiments.

In our contextual interviews, participants expressed that the inaccessibility of digital artboards contributes to significant educational and professional barriers for them. Furthermore, we found that the key problems faced were: (1) high cognitive loads from a lack of feedback about artboard contents and state; (2) difficulty determining relationships among artboard objects; and (3) constant uncertainty about whether object manipulations were successful. Many of these problems are illustrated in Figure 1.

The main contributions of this research are: (1) results from contextual interviews of 12 blind users about their need for and experience of digital artboards, which are widespread and frequently used in many professional and educational settings; (2) results from a task-based usability assessment of the artboards that appear in Microsoft PowerPoint and Google Slides with 12 blind users, revealing breakdowns, workarounds, and design opportunities; (3) design priorities for remedying the problems discovered. To the best of our knowledge, ours is the first study of the accessibility of 2-D artboard-style digital canvases with blind people.

2 RELATED WORK

Prior work related to the current research exists in three categories, which are reviewed below. These categories are (1) the social contexts of accessibility, (2) alternative modalities for communicating visual information non-visually, and (3) accessible creativity tools.

2.1 Social Contexts of Accessibility

Prior work has considered the cultural and social contexts of (in)accessibility. Shinohara and Wobbrock [48] investigated how assistive

technology usage is affected by perceptions of social accessibility and stigma, and Shinohara et al. [46, 47, 49, 50] further explored these implications and design tenets in subsequent work. Bennett et al. [5] introduced interdependence as a frame for assistive technology design, arguing that interdependence, as opposed to dependence or independence, allows for the recognition of the labor put into creating access by people with disabilities, as well as to reveal the relational nature of disability and accessibility.

Research concerning social contexts of accessibility for blind and visually-impaired people includes Das et al.'s [17] investigation of the ways in which ability-diverse teams involving people with and without vision impairments use collaborative writing tools, finding that people with vision impairments regularly learn and maintain an "ecosystem" of tools with varying levels of accessibility, and emphasizing that *accessibility* is not the same as *usability* (see also [6, 32, 40, 51, 52]). Branham and Kane [12] also examined how blind employees manage accessibility in ability-diverse workplaces, noting that the most commonly reported accessibility challenges in the workplace were related to computer software.

Lundgard et al. [33] proposed eight sociotechnical considerations for accessible visualization design, which included (1) considering whether technological intervention is appropriate in the first place, (2) evaluating whether the goal of the project is primarily "research," "design," or possibly both, (3) using participatory methods, (4) clearly communicating the researchers' intentions and expectations to all collaborators involved, (5) compensating people with disabilities involved in a design project "at a rate commensurate with their specialized skills, such as the ability to read Braille or use a screen reader," (6) being familiar with major accessibility guidelines, (7) considering the accessibility of specialized materials and technologies that may be involved in a design solution, and (8) ensuring that technologies used can effectively code and convey information at a resolution appropriate for the user's needs.

2.2 Non-Visual Information Delivery

We organize non-visual information delivery into three different output modalities: audio output, haptic output (further divided into active and passive haptics), and multimodal (audio-tactile) output. Extensive research has been conducted into each of these modalities over the past two decades, which demonstrates the challenges and opportunities in this design space. Given the extensive work in this area, a complete review is beyond the current scope. Rather, we focus on prior work relevant to creative applications or applications for blind users.

Audio Output. Brown et al. [14] presented guidelines for audio presentation of graphs and tables, noting that the major limitation of this modality was the load on the user's working memory. Additionally, they found that non-speech sounds lowered the user's perceived workload when completing tasks. Previous work has sonified maps and graphs [16, 18, 30]. EdgeSonic [56] sought to automatically sonify graphical information in apps and images, which users could access by sliding their finger over edges (e.g., the edge of a mountain against the sky). It also included "distance-to-edge sonification," which guided users towards sonified edges. Similarly, Access Overlays [28] demonstrated multiple techniques for audio-based navigation of large touchscreens. Other projects, like

evoGraphs [45] sought to improve the alternative text for graphs, making it easier to understand screen-reader output.

Active Haptics. Advances in vibration technology have allowed for more successful translation of graphics into tactile representations. Researchers have used electrovibration [54] and variable friction surfaces [35, 36] in addition to working with existing, commercially-available vibrating touchscreens [1, 2]. Palani et al. [39] have shown the key usability parameters for haptically rendering graphical lines and angles. Prior work has explored using haptic systems as an alternative to ALT text (e.g., [20, 35, 53, 54, 57]), but these and other custom solutions require specialized hardware and cannot easily be deployed at scale. Prescher et. al's Braille Window System [44], now referred to as HyperBraille, uses a touch-sensitive pin-matrix display to provide different text- or graphics-based views of windows in Braille.

Passive Haptics. Meanwhile, Kane et al.'s [29] Touchplates used plastic guides that may be 3-D printed, laser-cut, or made by hand that interact with touchscreens to provide tactile feedback. T-Draw [31] allowed a user to create a digital drawing while using a heat pen on swell paper for immediate tactile feedback. Lundgard et al.'s [33] case study involved the creation of 3-D printed tactile graphs for blind students.

Multimodal Output. There has been much research on multimodal output, so we focus on representative examples of multimodal output design solutions for blind and visually-impaired people. Wall and Brewster [53] presented guidelines for using tactile feedback to augment audio navigation, noting that haptic feedback can be used when it is most analogous to visual representations (e.g., heights of bars and paths of lines), while audio feedback may be used to represent fine-grained information, like texture cues. They also asserted that non-visual representations should attempt to preserve the structure of the visual representation in order to better facilitate communication and collaboration between sighted and blind people working with the same data.

Research in this area includes various methods of combining modalities [20, 26, 38, 43]. Additionally, prototypes have used supplementary devices in tandem with computers, tablets, and smartphones to achieve multimodal input/output. For example, vibrators attached to fingers [21, 37] have been used for this purpose, while smartwatches [4, 15, 41, 55] have been particularly popular in solutions that do not necessitate the creation of specialized hardware. Recently, Engel et al. [19] investigated digital pens as a mobile option to augment audio-tactile graphs.

2.3 Accessible Creativity Tools

As Bornschein and Weber [11] observed, there have been projects (e.g., [11, 22, 27, 31]) that support digital drawing for blind people. Some prototypes (e.g., [7, 8, 31]) have used analog methods for tactile output. For example, TDraw [31] utilized a heat pen on swell paper that allowed for continuous tactile feedback for blind users. The pen was digitally connected to the system so that user's drawings were rendered digitally as well, and the user could augment their drawing with verbal information through speech input.

Several prior projects have focused on vector graphics, i.e., artboards. The Tangram Workstation [9, 10] is a vector-graphics drawing workstation for blind users that utilizes a two-dimensional refreshable pin matrix display. Other solutions have not used extra hardware. AudioDraw [9] used touchscreen input and audio and text-to-speech (TTS) feedback to allow users to select and place pre-drawn shapes. In IC2D [27], Kamel and Landay used a 3×3 grid metaphor, recursive to three levels of refinement, which allowed users to make line drawings, polygons, and circles with keyboard input.

Recently, Potluri et al. [42] explored the potential of AI assistance for blind and low-vision creators making user interface designs with sketches or Wikki-Stix, which are then interpreted by an AI system as digital designs. Potluri et al. [43] also introduced a multi-modal system for blind and visually-impaired user-interface designers that allows the designer to modify visual elements with a touchscreen and modify code on a computer.

Others have created accessible creativity tools for other disability groups. Harada et. al. [23] designed VoiceDraw, which used continuous non-speech voice input as a modality to facilitate continuous manipulation of the paintbrush, allowing users to draw without the use of their hands. The brush head could be moved to the desired location using a circular soundmap of vowel sounds. EyeDraw [24] was a similar program aimed at children with severe motor disabilities to draw with eye-tracking technology.

This work demonstrates that blind creativity and productivity tools are a challenging design space that requires continued innovation as new technologies are integrated into nonvisual accessibility. However, to our knowledge, no research has been conducted into blind users' experiences with artboard programs.

3 METHOD

The primary goal of this study is to understand the needs of and issues faced by blind users of artboard programs. To do so, we conducted a mixed-methods study in two phases. In Phase 1, we conducted contextual interviews of 12 blind participants about their experiences with artboards, directly observing them creating using an artboard program of their choosing. In Phase 2, we evaluated the current state of artboard accessibility by running task-based usability tests with 12 blind participants, 9 of whom had participated in Phase 1.

3.1 Phase 1: Contextual Interviews and Observations

In order to gain an understanding of participants' past and current experiences with artboard programs, we conducted contextual interviews to learn about their history and contexts of artboard use and specific challenges they had encountered, and then observed them as they demonstrated how they use an artboard of their choosing.

3.1.1 Participants. We recruited 12 blind participants (5 women, 7 men, self-reported) through university mailing lists. Participants had an average age of 34.5 years (age range: 18 to 51, $SD = 9.9$ years). Participants self-reported all demographic data (see Table 1). To screen for the study, we required that participants be blind and primarily use a screen reader to access a computer, and confirmed

ID	Age	Gender	Vision Level	Health Condition	Screen Reader Used	Artboard Programs	Program Used	Phase 1	Phase 2
1	26	(W)oman	LP	N/A	JAWS	P, Adobe Illustrator	P	✓	
2	26	W	N	Retinal detachment	NVDA	P, K	P	✓	✓
3	35	W	N	Leber congenital amaurosis	JAWS	P, G	P(1), G(2)	✓	✓
4	42	(M)an	SV	Retinitis pigmentosa	NVDA	P	P	✓	✓
5	25	M	N	N/A	VoiceOver	P, K	P, K	✓	
6	35	M	N	N/A	JAWS	P, G, K, Zeplin	P(1), G(1, 2)	✓	✓
7	29	M	LP, SV	N/A	JAWS, NVDA	P, G	P	✓	✓
8	47	M	LP	N/A	JAWS	P	P	✓	✓
9	18	W	N	Unknown condition	NVDA	P, G	P	✓	✓
10	40	M	SV	Retinitis pigmentosa	JAWS	P, G, K	P	✓	
11	40	M	SV	Retinitis pigmentosa	JAWS	P	P	✓	✓
12	51	W	N	Excessive oxygen as infant	JAWS	P, G	P	✓	✓
13	56	W	N	Macular degeneration	JAWS	P, G	P, G		✓
14	48	M	SV	Retinitis pigmentosa	NVDA	P	P		✓
15	55	M	N	N/A	JAWS	P	P		✓

Legend:

Vision Level: SV=Some Vision, LP=Light Perception, N=None.

Artboard Programs: P=Microsoft PowerPoint, G=Google Slides, K=Apple Keynote.

Program Used: (1)=Program used in Phase 1, (2)=Program used in Phase 2.

Table 1: Participant details including age, gender, vision level, health condition, screen-reader used in the study, artboard programs they are familiar with, the program(s) they used in the study, and which phases they participated in.

this with the participant over email before scheduling sessions. Six participants had no vision at all, two had some light perception, and four had some vision but were legally blind. We provided participants with a list of common commercial artboard programs, including popular digital presentation programs and vector-based drawing programs. Participants indicated which programs they were familiar with before identifying which program they would prefer to use during our observations. Participants were compensated with a \$25 USD Amazon gift card for about 60 minutes of their time.

All participants were familiar with Microsoft PowerPoint. Four of them were also familiar with Apple Keynote, and another four with Google Slides. Two participants were familiar with all three. P1 had tried Adobe Illustrator in the past, and P6 was also familiar with the design-collaboration application Zeplin. All but one participant chose to use PowerPoint 2016 during our observations; P8 used PowerPoint 2010. Two participants (P5 and P6) chose additionally to demonstrate Keynote 10 and Google Slides, respectively.

3.1.2 Apparatus. Because of the prohibition on in-person studies due to COVID-19, all interview sessions were conducted remotely using the video-calling software Zoom. Participants used their own computers, all but one of which was running Windows. Nine participants used the Freedom Scientific JAWS screen reader, four used NV Access NVDA, one used both, and one used Apple VoiceOver. Participants shared their screens and computer audio during our observations. The researcher recorded video and audio from all sessions with Zoom’s recording feature.

3.1.3 Procedure. Sessions were divided into two halves: (1) a contextual, semi-structured interview about the participant’s experiences with artboard programs, and (2) a think-aloud observation of the participant creating a presentation in their preferred program.

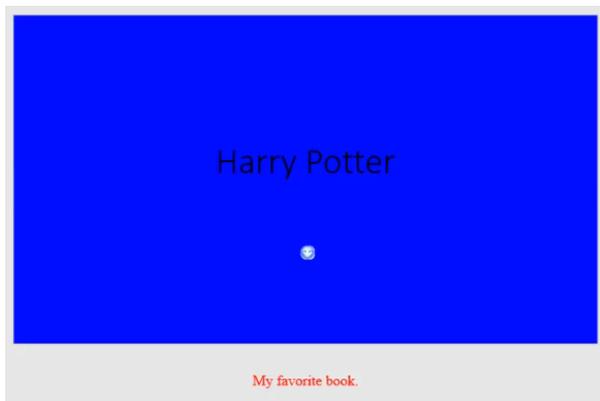
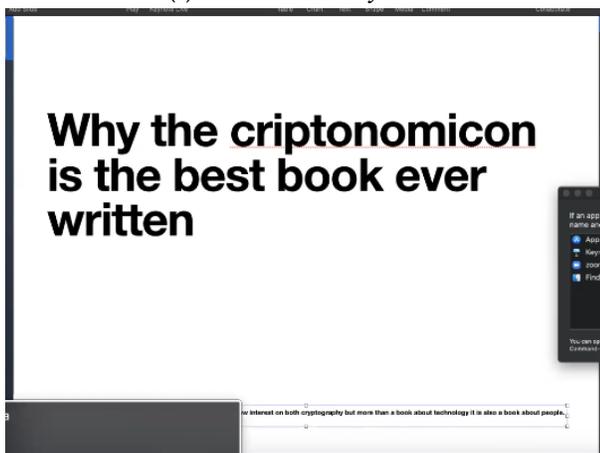
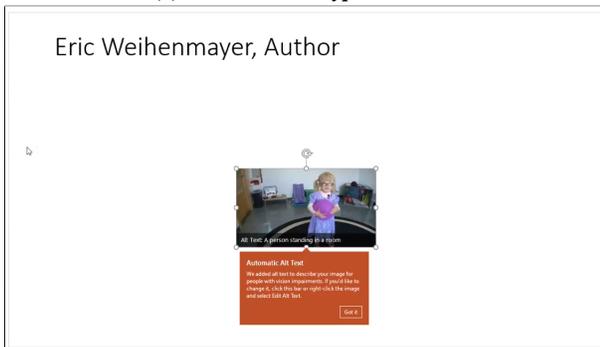
At the beginning of the session, participants were asked for permission to record, and for their demographic information if they had not yet given that information to the research team.

During the interview, we asked participants questions about their use of artboard programs to identify their motivations, contexts of use, and any challenges they encounter (e.g., “Think of a specific time you had to access an existing presentation, which could be one that someone else made or one that you made. Can you tell me what that presentation was, and what it was about?”). Participants were asked about specific times they had accessed artboard projects that someone else made, and about occasions when they made their own. Participants were also asked about how the experiences made them feel, and, if they encountered problems, what features they could imagine might have helped prevent, mitigate, or solve that problem.

During our observations of participants creating artboard projects, we asked them to demonstrate how they interact with their preferred program by making a brief presentation about their favorite book or animal (see Figure 2). Participants were asked to think aloud as they made the presentation and were encouraged to add a relevant graphic to the presentation so the researcher could observe how they did so. At the end of the session, participants were asked briefly how they felt while creating their presentation.

3.1.4 Design and Analysis. All sessions were recorded and transcribed. Transcription was performed by either a member of the research team or a professional transcription service, whose transcripts were then verified by the first author. We employed thematic analysis [13] to analyze the interview and observation sessions. Our study data consisted of 13 hours 8 minutes of transcriptions.

The first author familiarized herself with the transcript material as well as relevant screen recordings from sessions, and took note of patterns that quickly emerged, then began coding transcripts focusing on participant emotions such as uncertainty, confusion, frustration, and exclusion, and common problems participants had

(a) P1's slide on *Harry Potter*.(b) P5's slide on *Cryptonomicon*.

(c) P7's slide on Erik Weihenmayer.

Figure 2: Three artboards created by participants during the Phase 1 observation. In (a), P1 made a PowerPoint presentation on J. K. Rowling's *Harry Potter*, and wanted to make the slide more engaging by adding color. In (b), P3 made a Keynote presentation on Neal Stephenson's *Cryptonomicon*. P3 thought the subtitle placeholder was directly below the title, but the subtitle was much smaller and located at the bottom edge of the artboard, which made it difficult for a sighted person to read. In (c), P7 searched for a photo of the author-adventurer Erik Weihenmayer but ended up with a photo of a young child that was attached to an article about him.

that involved a lack of information, unhelpful information, or a complex interface. The researchers coalesced these patterns into four themes: (1) high cognitive load, (2) object relationship determination, (3) object manipulation success confirmation, and (4) education and professional barriers caused by artboard inaccessibility.

3.2 Phase 2: Task-Based Usability Tests

For the second phase of the study, we wanted to understand the current state of artboard accessibility by conducting task-based think-aloud usability tests with artboard programs of participants' choosing.

3.2.1 Participants. Participants for the second phase were recruited first by asking participants from Phase 1, our interviews and observations phase, to participate, and then by recruiting people who had originally expressed interest in Phase 1 but were ultimately unable to participate in it. In this manner, we recruited 12 participants (5 women, 7 men, self-reported), nine of whom were from Phase 1, with an average age of 40.2 years (range: 18 to 56, $SD=11.9$). Six participants had no vision, one had some light perception, and four had some vision but were legally blind. New participants were screened and asked the same questions about artboard programs and demographic information as in Phase 1. Participants were compensated with a \$25 USD Amazon gift card for about 60 minutes of their time.

All but four participants used Microsoft PowerPoint 2016 for the duration of their session. P8 used PowerPoint 2010; P3 and P6 used Google Slides; and P13 used Google Slides for Part 1 and Microsoft PowerPoint for Part 2 due to technical difficulties with both programs.

3.2.2 Apparatus. The apparatus used in the task-based usability tests was nearly identical to that used in Phase 1, above. However, one additional item used was a pre-designed artboard created by the first author (see Figure 3a). The pre-designed artboard was used for interpretation tasks, which are tasks #1-11 (see Figure 3b).

The research team collaboratively designed a task list and protocol informed by the preliminary findings of Phase 1. The "building blocks" of artboard interactions were identified and tasks were designed to evaluate the accessibility of each of these key artboard interactions. For tasks #1-11, participants were asked to determine information about objects arranged on the pre-made slide, which was constructed to test pain points identified by participants in Phase 1. All screen readers used in our observations announced objects on the artboard in an order determined by objects' Z-order, which is the overlapping vertical order of objects. Objects added to an artboard are, by default, added on top of the Z-order, meaning they will appear on top of other objects and be read last by the screen reader. But the Z-order has no relation to the (x,y) position of an object on a slide, and therefore has no relation to the left-to-right or top-to-bottom ordering of objects. Because of this issue, the artboard was intentionally constructed to be difficult for a screen-reader user to accurately interpret its layout: the objects were added "out of order," so that a screen reader would read the rectangle first, then the arrow, oval, and text box. Objects were different colors to test color-identification program features.

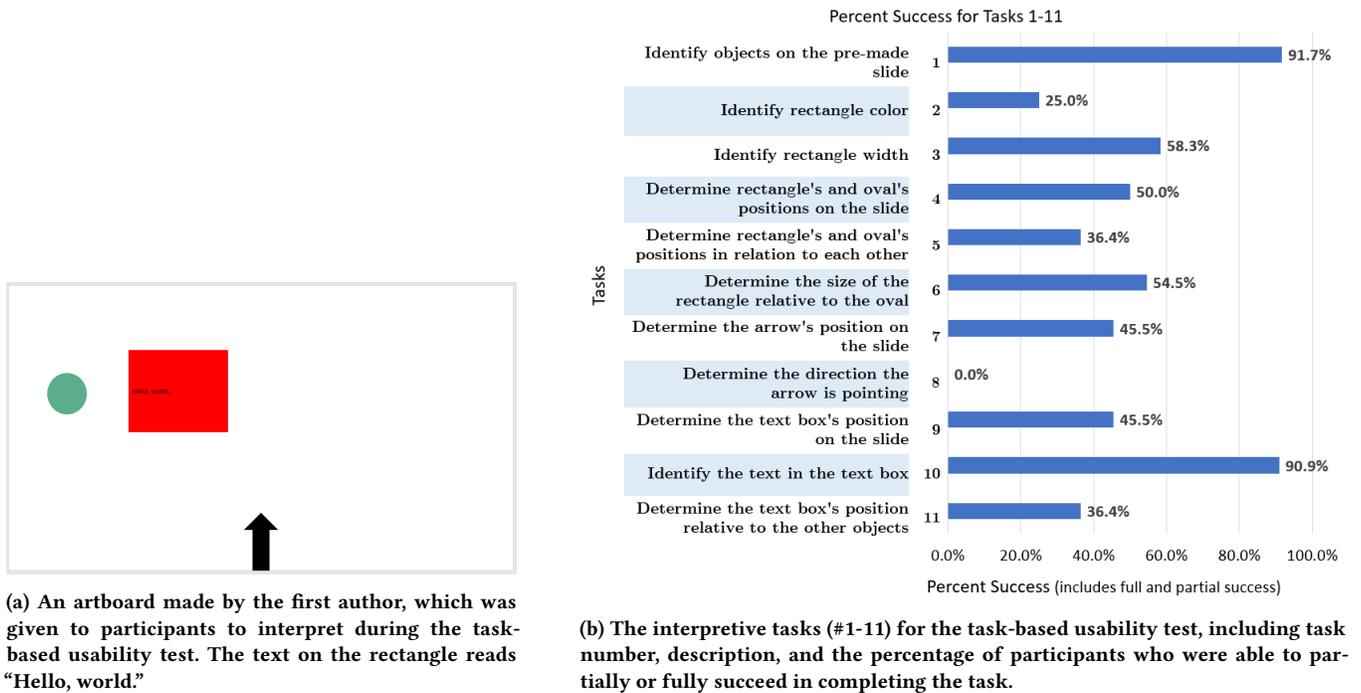


Figure 3: Participants examined a pre-made artboard in tasks #1-11 of the task-based usability test. Note in 3b that identifying what an object is (#1, #10) had the highest success rate, while relative positions (#5, #11) had low success rates. Success for #2 seemed to be dependent on the screen reader being used. The label of the arrow as a “right arrow,” because it was rotated, misled participants.

3.2.3 Procedure. To better understand blind users’ interactions with artboards independent of the surrounding digital presentation programs in which they reside, we devised 23 tasks focused on understanding and manipulating visual and spatial information of artboard objects (see Figures 3b, 4). At the beginning of each session, participants were asked for permission to record, and were told that they would perform two sets of tasks: tasks #1-11 dealt with content *interpretation*, that is, understanding the contents of a pre-existing artboard; tasks #12-23 dealt with content *generation*, that is, placing and manipulating objects on a new artboard (see Figure 4). Tasks were deliberately formulated using some relative spatial terminology so that we could understand how participants might interpret terms like “next to,” “top,” “bottom,” “left,” and “right.” For tasks #12-23, participants were asked to create a new slide and were asked to place and manipulate objects on that slide.

Participants were asked to think aloud as they performed the tasks. Tasks were read out-loud to participants one at a time, and were timed starting when the participant indicated they understood the task and stopping when the participant either told the researcher their answer (for interpretive tasks), or told the researcher they were done with the task (for generative tasks). We defined an “accessible task” as one that could be completed successfully within five minutes, so participants were also stopped on a given task if they exceeded that time. Participants also had the option to quit a task before they reached five minutes if they felt that they simply could not complete the task, or if they grew too frustrated.

Because we were focusing on the artboards themselves and not on the “surrounding chrome” of the application, the researcher gave assistance to participants if a problem arose that was particular to the software application apart from the artboard. For example, participants using Microsoft PowerPoint often had difficulty finding the shapes menu and could get blocked from task panes that did not allow keyboard focus to return to them once opened. Although such accessibility problems could be dire, they were considered beyond the scope of the current investigation, which was focused on artboards.

At the end of the session, participants debriefed with the researcher about how the session went, and were asked about how they felt and what they experienced while performing the tasks.

3.2.4 Design and Analysis. All sessions were recorded and transcribed in the same manner as those from Phase 1, our contextual interviews and observations phase, and the sessions and field notes were included in our thematic analysis [13]. Our study data consisted of 13 hours 8 minutes from the first phase and 14 hours 9 minutes from the second phase, for a total of 27 hours and 17 minutes. Quantitative data about task success rates and task durations were analyzed as descriptive statistics characterizing user behavior and task accessibility to understand which types of tasks were most challenging and why.

Our usability tasks were coded as follows: (1) success, (2) partial success, (3) thought (incorrectly) to be a success by the participant,

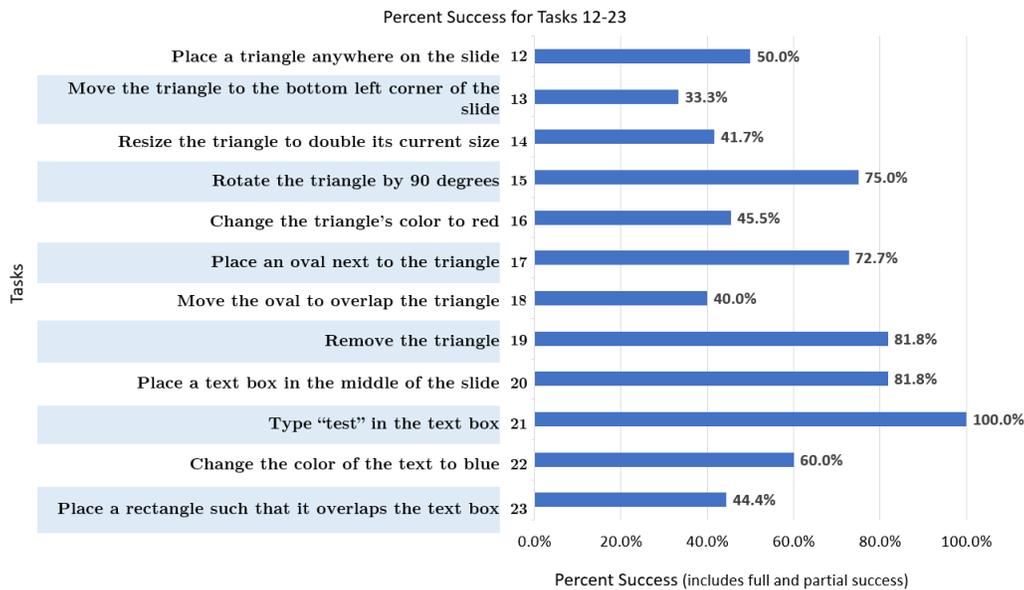


Figure 4: The generative tasks (#12-23) for the task-based usability test, including task number, description, and the percentage of participants who were able to partially or fully succeed in completing the task. During these tasks, participants were asked to produce and manipulate artboard content. Six tasks in this group (#15, #17, #19-22) had success rates of 60.0% or higher, while only two from tasks #1-11 (#1 and #11; see Figure 3b) performed the same.

(4) participant quit, (5) participant timed out, or (6) participant chose not to attempt. Tasks were considered a “success” if the participant was able to complete the task as it was described to them and was able to confirm for themselves that they had completed it. A task was coded as a “partial success” if participants (a) completed part of the task but not all of it, (b) completed the task but were not able to confirm for themselves that they had done so, or (c) completed an aspect of the task but not the task in its entirety. Respective examples of partial successes would be if a participant determined the rectangle’s position but not the oval’s position in task #4; or, if a participant changed the color of the triangle to red but was not sure the change had occurred in task #16; or, if a participant successfully determined an object’s position on the Y-axis but not on the X-axis in task #9. Any tasks coded as a timeout (5) were treated as lasting five minutes in timing calculations (e.g., Figure 6).

Figure 3b and Figure 4 list the tasks performed and the percentage of participants who were able to partially or fully complete each task. Three of 12 participants were unable to perform all of the tasks because of technical difficulties during the session: P2 did not have time in the session to complete tasks #5-11 and task #23; P3 did not have time to complete tasks #16-23; and P5 did not have time to complete tasks #21-23. Most participants performed the tasks in numerical order, but three (P9, P11, and P14) started with tasks #12-23 and then performed tasks #1-11. We conducted 12 sessions with 12 participants, 9 of whom completed 23 tasks each; 3 of whom completed 15, 16, and 20 tasks, respectively. Thus, our data for Phase 2 consisted of $9 \times 23 + 15 + 16 + 20 = 258$ tasks completed.

4 RESULTS

We organize our findings from Phase 1, the contextual interviews, and Phase 2, the task-based usability tests, into five sections: (1) educational and professional barriers, (2) general observations from both phases of the study, (3) high cognitive load, (4) difficulty determining relationships among objects, and (5) uncertainty about object manipulation success.

4.1 Educational and Professional Barriers

In our interviews, every participant brought up digital presentation accessibility as a barrier in school and work, due to the ubiquity of digital presentation programs in both contexts. The nature and impact of these barriers varied and can be grouped into three broad themes: feelings of exclusion or isolation from sighted peers or colleagues, a lack of accessibility knowledge among sighted authors, and the experience of barriers to their own authorship. We expand upon each of these themes, below.

4.1.1 Feelings of Exclusion. Two participants noted feeling excluded or isolated due to the inaccessibility of digital presentations, particularly the artboard component. P1 said she had experienced group work in classes where she was excluded or became uninvolved in group projects because “when I’m working with slides with other people, they don’t put alternative text or anything in their pictures. So, I don’t even know what their slides are like,” even after she had asked them to make slides more accessible. “I’m just basically the one that nobody wants,” she concluded. P3 reported feeling isolated at work when she and other visually impaired team members were unable to follow a meeting because most of the

content was in an inaccessible presentation: “We were like, we’re here in the meeting, but we don’t know what we’re doing, because they were pointing and talking about it, but they were not really talking in a way that would make sense to a totally blind person.”

P7 and P10 noted that this kind of inaccessibility contributes to the ongoing exclusion of blind people in the workplace. P7 pointed out that “we have to find creative ways to solve the same problems” a sighted person can do almost instantly, with a tool designed without blind people in mind: “A blind person with a screen reader is going to take five, maybe [for] some things two to five, times more time than the sighted person. ... Only in the eye of the employment world, in the business world, that is not the best way to do it.” Similarly, P10 noted that he feels he was able to reach the executive position he is in partly because he has a good memory and is capable of conceptualizing systems in his head. While a sighted person with more limited recall can be aided by a chart or diagram, P10 observed that a similarly situated blind person could not necessarily do the same.

4.1.2 Others’ Lack of Accessibility Knowledge. Several participants observed that, in their experience, sighted users did not often utilize ALT text in their presentations; if they did, it was not always done correctly. Sighted users also had little knowledge of how screen readers work. P10 and P12 both reported experiences of sighted authors putting screenshots of text in presentations, not realizing that screen readers could not interpret it. P8 commented that a lot of professors “are kind of oblivious to know[ing] how the screen reader will work,” which P5 echoed when talking about professors who labeled parts of a diagram without describing relationships between parts, or who labeled parts of anatomical images without describing other relevant information in the image. These participants noted that these situations occurred even when a presentation’s author knew that the participants would be reading their presentations.

4.1.3 Barriers to Authorship. Every participant interviewed was anywhere from “rather interested” to “very enthusiastic” about finding ways to create artboard projects, including presentations, without needing sighted assistance. P8 strongly desired to learn more about creating with Microsoft PowerPoint, saying, “most [blind people] have been readers, not creators, of content. It’s a very big hole that hasn’t been filled with people learning how to do it.” P10 commented that he tries to avoid making presentations when he can, “but I don’t want to have to avoid PowerPoint and diagrams and things like that.”

Most participants expressed concern for the visual appearance of presentations they created. P4 said that it was unfortunate that he had to avoid using images or tables in presentations because he felt that the purpose of a presentation was as a visual aid. P6 and P9 brought up wanting to make sure that they were including people who were visual learners when giving presentations. P7, P8, and P12 talked about wanting their presentations to be visually engaging to hold the interest of a sighted audience. As P8 said, “It’s got to look nice. It’s got to look professional. It can’t be haphazard ... If it looks disgusting and ugly and like a Mickey Mouse operation, people will just roll their eyes and they won’t even read it. They won’t even look; they’ll just look at the floor or whatever.”

Our participants emphasized that digital presentation programs in particular fall short of acceptable accessibility. P4 referred to

Microsoft PowerPoint as “accessible but not usable,” indicating that while accessibility options existed, much of the program’s features were unusable for him and other blind people, especially as an author using the artboard program. “The problem is fundamental,” P4 said. “They design it visually and then try to make it accessible non-visually.”

4.2 General Observations

In this subsection, we offer some general observations about our sessions with participants to characterize their experiences with artboards.

Participants expressed a range of emotions during the task-based usability tests: from annoyance, frustration, and confusion to surprise, curiosity, and playfulness. As participants continued through the tests, they grew more sure of their perceived self-efficacy, whether high or low: some participants grew more confident as they continued, while others felt more disoriented or determined that they were unable to complete certain types of tasks, such as discerning object positions (tasks #4, #5, #7, #9, #11) or moving objects (tasks #13, #17, #18, #20, #23).

As stated above, tasks during the usability test were divided into *interpretive* tasks (#1-11) and *generative* tasks (#12-23). As a reminder, tasks were coded as follows: (1) success, (2) partial success, (3) thought (incorrectly) to be a success by the participant, (4) participant quit, (5) participant timed out, or (6) participant did not attempt. A distribution of these codes over all sessions and tasks can be seen in Figure 5.

Time spent on each task can be seen in Figure 6. Task #4 took the longest of the interpretive tasks, as it was the first one concerning determining object positions; for subsequent related tasks, participants either continued to build a more complete mental model of the artboard — although it was not always accurate — or they chose to guess answers without being certain if they were correct. Note that more participants ran out of time during generative tasks than interpretive tasks (see Figure 5): six participants in total timed out of generative tasks, whereas only one participant timed out of one interpretive task (#2) as well as two generative tasks (#12 and #14). Tasks #12-17 had the highest variance in duration, as participants’ previous knowledge of operations such as moving options played a larger role in the time it took them to either complete, quit, or run out of time while performing those tasks. Most instances of tasks timing out occurred with this group of tasks as well.

Participants varied greatly in their success rates (full and partial successes included) for the different tasks. The average success rates for interpretive and generative tasks was 47.5% and 58.9%, respectively. For the interpretive tasks, P6 and P9 had the highest success rates of 81.8%, while P2 and P13 had the lowest at 18.2%. For the generative tasks, P9 had a full or partial success for 100.0% of the tasks while P3 and P12 had a 16.7% success rate. While it should be noted that P9 and P13 were the youngest and oldest participants, respectively, there was not a strong trend of higher success rates linked with lower ages. The median age of Phase 2 participants was 41 years. For interpretive tasks, two participants under 41 years and three participants over 41 years had a success rate equal to or higher than the average. For generative tasks, four participants

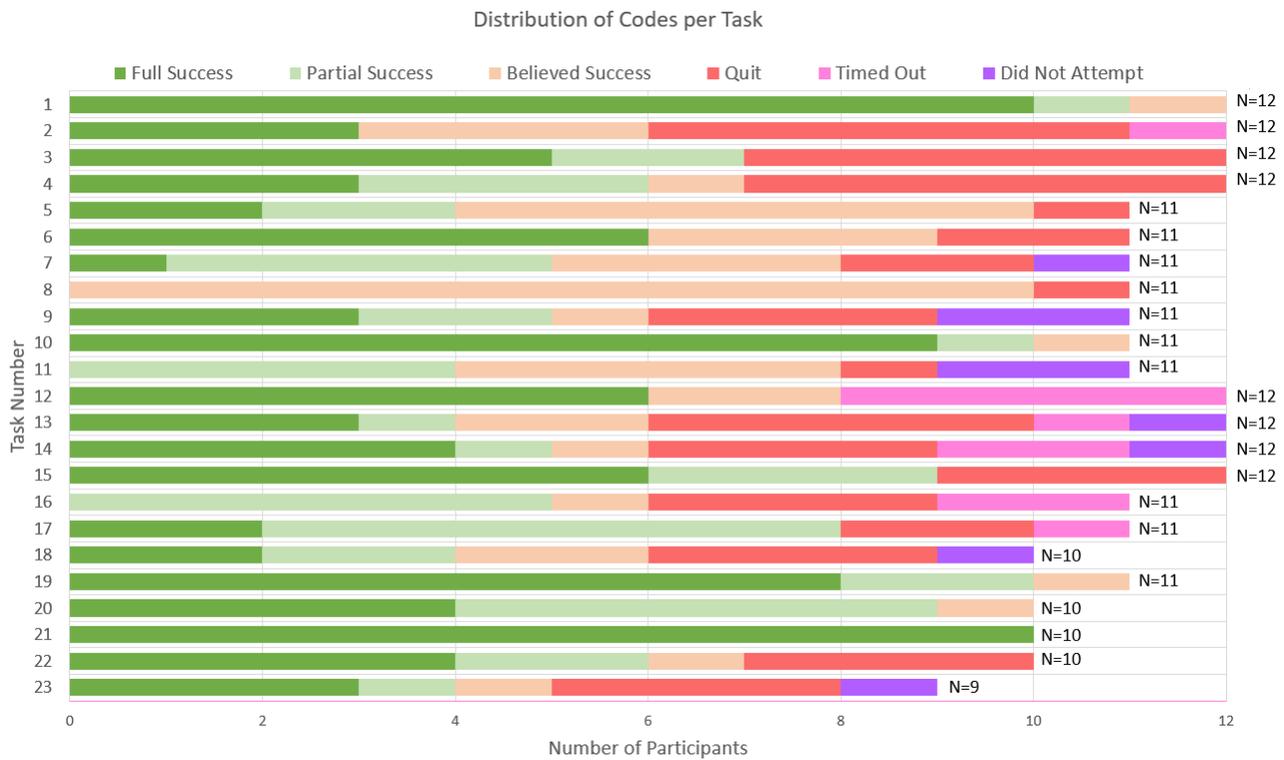


Figure 5: Distribution of codes per task, showing how many instances of each code tasks received over the course of the study. Full and partial successes are colored green. Note that more participants ran out of time during generative tasks (#12-23), and some participants did not have enough time in the allotted session to complete every task (#5-11, #16-18, #23), resulting in an N less than the total number of participants in the study. None of the participants were able to identify the direction of an arrow (#8), and none of the participants were able to both change the color of a triangle and confirm that the change was successful (#16), but more participants knew how to change text color from prior experience (#22).

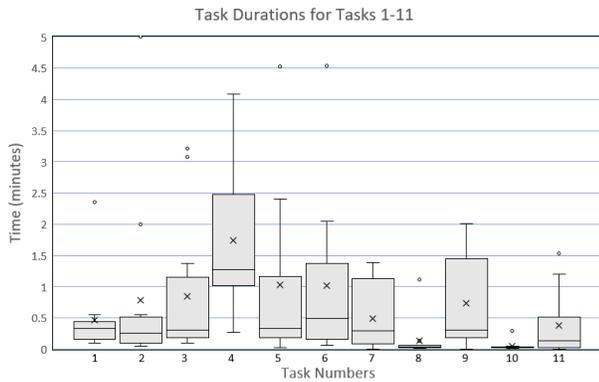
under 41 years and two participants over 41 years had a success rate equal to or higher than the average.

Five of the 11 interpretive tasks had an average success rate (full and partial successes included) of 50.0% or higher (#1, #3, #4, #6, and #10), while seven of the 12 generative tasks had an average success rate of 50.0% or higher (#12, #15, #17, #19, #20, #21, and #22; see Figures 3b, 4). The interpretive tasks with higher success rates had to do with finding measurements (e.g., sizes) or identifying artboard objects (#1, #10). Tasks that involved relationships between objects (#2, #5) or obtaining information that was difficult to find textually as opposed to visually (i.e., rectangle color and arrow direction) had lower success rates. Locating an object's position on the slide was split: tasks #5, #7, and #9 had average success rates between 45.5% and 50.0%. The generative tasks with higher success rates had to do with placing or removing objects (#12, #17, #19, #20), and tasks involving reading or formatting text (#21, #22), which participants were more familiar with. Interestingly, tasks #14 (resizing the triangle) and #16 (changing the triangle's color), the two shape formatting tasks, which had counterparts in the text formatting submenu, had slightly lower success rates than task #15 (rotating the triangle). P6, P11, and P12 experienced difficulties

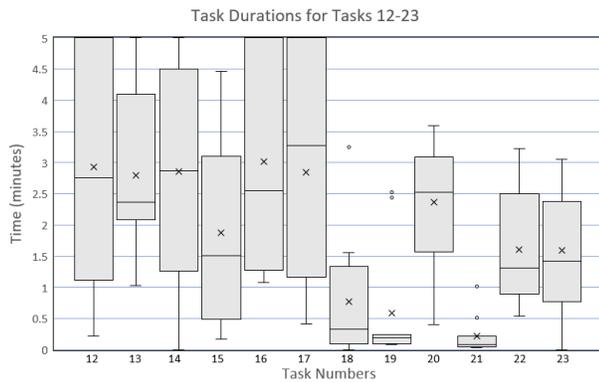
because of this, as the text formatting options are still selectable when the keyboard focus is on a shape with no text in it.

Only three of the 12 participants in Phase 2 used Google Slides instead of Microsoft PowerPoint as their preferred program (P13 used Google Slides for the interpretive tasks and PowerPoint for the generative tasks due to technical issues), so there is not enough data to infer how the programs may have influenced the study's results. However, we may draw tentative correlations between the screen-reader software and the results: five participants used NVDA and seven used JAWS (see Table 1), and those who used NVDA (P2, P4, P7, P9, and P14) had the highest success rates for the generative tasks. However, this is a correlation that likely has multiple contributing factors.

Participants had varying levels of experience with the artboard programs they chose prior to the study. Thirteen of the total participants reported the context in which they used artboard programs: five participants said they used artboard programs at work, four participants used them in school (high school, undergraduate, and graduate), and four participants used them in both school and work. All participants reported feeling comfortable with accessing artboard projects in their contexts of use provided they were accessible.



(a) Task durations for the interpretive tasks, #1-11.



(b) Task durations for the generative tasks, #12-23.

Figure 6: Time spent on each task had higher variance during generative tasks (#12-23), as some participants had either previous knowledge for performing those tasks or had to learn. Tasks #8, #10, #19, and #21 consisted of actions such as reading or adding text, which participants could complete very quickly. Note that some participants took less time on a task because they chose to quit the task rather than continue. If a participant timed out of a task, it was included as a duration of 5 minutes.

Seven participants (P4, P5, P8, P10, P11, P13, P15) said they were not very comfortable creating or editing artboard projects in their contexts of use; two (P3, P6) were somewhat comfortable; and four (P1, P2, P7, P9) were comfortable. P12 said her comfort level was dependent on the context: she enjoyed “playing around” on PowerPoint for personal projects, but was not as comfortable when she made slides for work.

The four participants who reported being comfortable with creating or editing artboard projects were all under 30 years old and had created presentations for school in the past. P2, P7, and P9, who participated in both phases of the study, also had higher full or partial success rates (>90%; average 58.5%) with generative tasks (#12-23). Drawing a correlation is somewhat tenuous due to the small sample size; P5 was the only other participant under 30 and was currently using presentation programs in college, but said that he found creating presentations “very hard” and usually asked

someone to do it for him. P5 did not participate in Phase 2, however. P3 and P6, both 35 years old, reported being somewhat comfortable with creating or editing artboard projects, and had used artboard programs in both work and school contexts, but had below average success rates with generative tasks (16.7% and 55.6%, respectively). Additionally, P11 (40 years old) and P15 (55 years old) said they had not created or edited artboard projects “in a long time” but performed near or above average with the generative tasks.

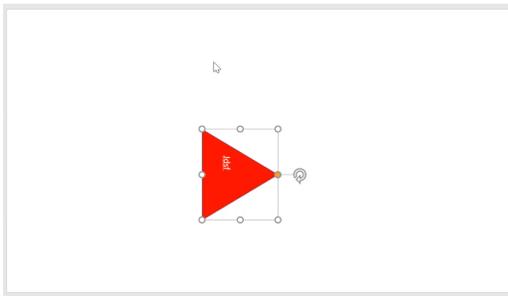
4.3 High Cognitive Load

Participants reported high cognitive loads from a lack of feedback about artboard contents and object state. Using a screen reader often requires a lot of working memory on the part of the user; however, participants felt that the cognitive load for accomplishing tasks such as determining the relative size or position of an object was unreasonably high. Participants struggled with remembering all of the information they were receiving, while simultaneously sorting out which information was actually needed, and then performing calculations in their heads to figure out how to complete a given task. As P2 noted, “It’s too much information and not enough at the same time.”

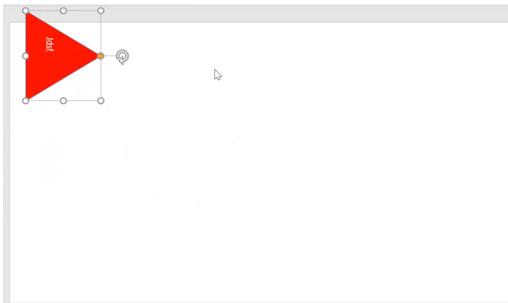
Many of the *interpretive* tasks (#1-11) in Phase 2 necessitated that participants remember a lot of information about the objects, as well as perform mental geometry. Screen readers announced positions of objects in different units depending on the screen-reader software being used; JAWS used inches and NVDA used points. Both screen readers announced positions in a coordinate system, e.g., “167 points from left slide edge” or “0.7 inches from the left, 1 inch from the top.” Determining the positions of the objects on the pre-made slide (see Figure 3a) meant that participants had to determine the X/Y position of the object and determine in which quadrant of the artboard the object was located. Several participants noted that they did not know the size of the artboard in the first place, so the numbers were meaningless until they had enough information to calculate relative positions. For example, “73 points from top slide edge, 245 points from bottom slide edge” indicated to P8 that an object was closer to the top than the bottom. P7, on learning that the triangle was 2.7 inches wide, commented, “I know to touch the triangle would probably be the size of my fingers almost put together but on relation to the slide, I don’t know.”

None of the participants had success with task #8 (determining the direction of the arrow on the pre-made artboard) because the arrow was a “right arrow” from the artboard’s shapes menu, rotated to point up, but participants were misled when their screen readers announced it as a right arrow. P6 was able to identify that the arrow was “twisted counterclockwise” while completing task #7 (determining the position of the arrow), but said that it was pointing to the right when he completed task #8; by that time having forgotten what he had noticed in the previous task due to the amount of information he was receiving from the program.

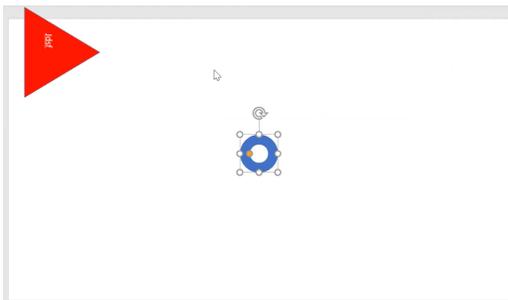
Participants struggled to remember all of the objects’ positions, and often had to recalculate an object’s position for one task when they had just calculated it for the previous task. P6, when he had to determine where the text box was in relation to the other objects on the pre-made slide commented, “I don’t remember the dimensions of the other now,” and guessed that the text box was the furthest



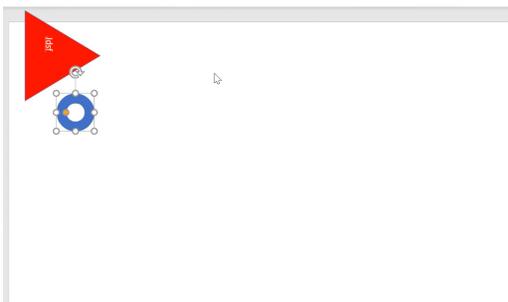
(a) P9's triangle is positioned near the center of the artboard, but she is not sure where it is.



(b) P9 moves the triangle to the upper left corner of the artboard.



(c) P9 adds an oval, which is placed by default in the center of the artboard.



(d) P9 moves the oval next to the triangle.

Figure 7: P9's artboard state as she attempts to place an oval object next to a triangle object. She first moves the triangle to a position she can remember and move the oval to, but then forgets where she placed the triangle and has to determine its position again. Once she does so, she moves the oval so it is below the triangle, the bounding boxes overlapping.

left of the objects. P8, after determining the positions of the rectangle and the oval on the artboard in task #4, had to begin his calculations anew when he was asked in the next task to determine their positions relative to each other. After nearly 2.5 minutes, he realized he had already calculated them and went through his JAWS history to find the answers. P8 was surprised when he realized that, saying, "I don't know why I got mixed up, because, for some reason, I just lost track of the fact that originally we did do the oval and the rectangle." P8 also said he considered opening Microsoft Notepad or Excel to take notes in "rows and columns, like height, width, distance from left, distance from right, and then I could just toggle through."

While completing tasks in Phase 2, a few participants developed workarounds to lessen the cognitive load. Like P8, P6 at one point opened up his JAWS history to re-read the list of coordinates he had just heard (see Figure 8). In another instance, when P9 needed to place an oval next to an already-placed triangle (see Figure 7a), she first moved the triangle to the top-left corner of the artboard so that she would know which direction to move the oval as well (see Figure 7b). She explained that it would be easier to remember the coordinates that way, likely because the numbers the screen reader announced were smaller (it now announced "16 points from left slide edge" instead of "350 points from left slide edge"). However, by the time she had navigated through the menu to find and place an oval (see Figure 7c), she did not remember where she had placed her triangle and had to re-determine its position. If she had received clearer feedback about object placement and position, she would have known that objects are added to the center of the artboard by default, which was where the triangle was before she moved it.

A workaround reported by two participants in the contextual interviews was using the mobile version of an artboard program because it typically features a pared-down menu. P3 said that she uses Google Slides on her phone more often than on her desktop computer because it does not have as many menu items and the buttons are "pretty [well] labeled" in comparison to the desktop version. P5 also said that he found it was more accessible to read presentations on his iPad (with an external keyboard connected) than on his Mac, saying that he found "the commands are easier because it's more focused."

Some participants reported reducing their cognitive load by translating some or all of an artboard into a tactile format. Two participants (P2 and P3) said that they sometimes used Braille displays for notes while presenting (P3 also used one for taking notes during others' presentations) in order to reduce the cognitive load of listening to their slides and their notes while speaking. P5 preferred to read lecture presentations entirely on his Braille display unless they included math formulas or code samples, which he instead had embossed on paper by his school's Disability Services, commenting that "reading math on a Braille display is the gateway to Hell." In another instance, during the task-based usability study, P7 attempted to use his computer's touchscreen while determining the positions of the rectangle and the oval in task #4 by running his finger across the screen, hoping his screen reader would announce the objects when he passed over them. However, he reported that he knew the menu ribbon was at the top of the screen and the artboard was below it, but was not able to find the shapes.

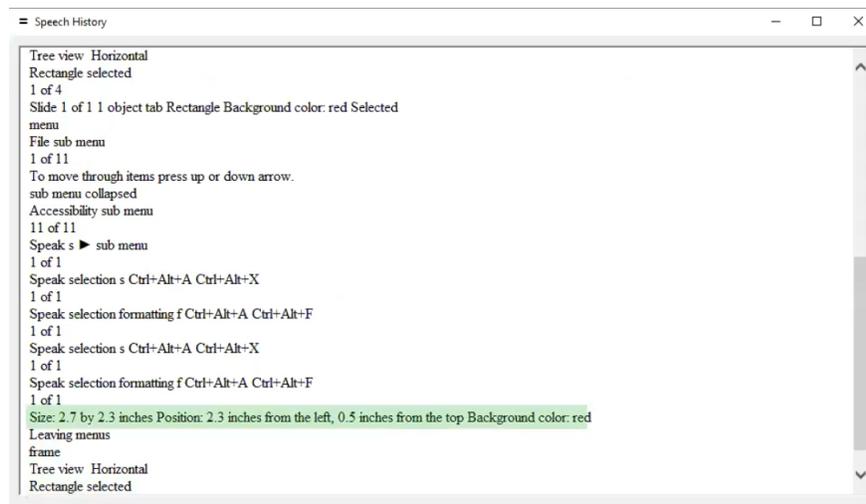


Figure 8: P6 opens up his JAWS history to remember the information about the rectangle that he could not remember. P8 also used his JAWS history to refresh his memory.

High cognitive loads were not just produced by a lack of feedback. They were also exacerbated by other things screen-reader users have to remember, like program-specific keystroke commands. Several participants noted that, while keystroke commands are common accessibility solutions to reduce time spent navigating program menus, these commands are not as useful when they are not discoverable, do not follow conventions, or are overly complex. P8 pointed out that it does not feel worthwhile to memorize “10 or 20 or 30 keystroke commands” when “all I want to do is[, for example,] sort.” P4 also commented that sighted designers “assume that blind people have an elephant memory,” so adding keystroke commands to a program, while helpful, is not an accessibility panacea. P7, too, noted that “hunting down” and remembering keystroke commands is “just like any other thing that the blind community has to get used to: memorizing things, unfortunately.”

4.4 Difficulty Determining Relationships Among Artboard Objects

Participants consistently encountered challenges related to understanding relative positions of objects on the artboard, and the relationships among objects. In interviews, several participants said that while they relied on slide templates to ensure objects remained organized, they did not know how those templates were spatially laid out. P7 said that he did not know what templates looked like and would have to use Aira, an application that allows users to share their screen or camera with a sighted helper to understand an object’s position, even if it was in a template placeholder. Meanwhile, P1 expressed surprise when she determined the layout of a default title card template while moving an image so it would not overlap the title and subtitle placeholders. As she moved the image, her screen reader announced when it was overlapping one of the placeholders, so she was able to use the image like a cane, moving it in different directions until it “ran into” a placeholder, which helped her understand the artboard’s layout. Later, she commented,

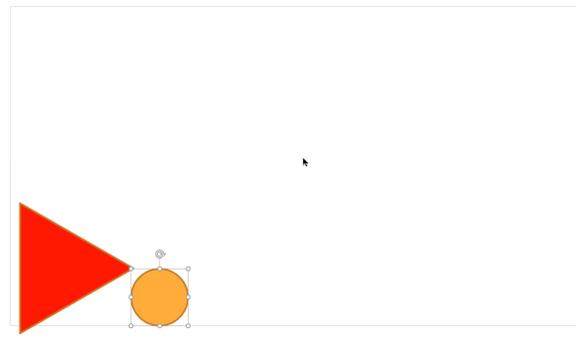


Figure 9: An artboard’s state after P7 completed task #18, which was to move an oval so it overlapped with a triangle. P7’s screen reader announced that the two objects were overlapping when the oval’s bounding box overlapped with the triangle’s bounding box, but to a sighted viewer, the shapes do not appear to overlap.

“I didn’t know until I started moving [the image] that the subtitle placeholder is underneath the title placeholder. I thought it was to the right of it.” P9 succinctly summarized her experiences with determining object positions and relationships as “very tedious.”

In Phase 2, seven of the 12 participants were able to obtain positional information about the artboard objects, but most found it unhelpful or difficult to understand. Screen readers announced when objects overlapped each other (e.g., “covers right of other item by 65 points”), although this output was determined by whether the objects’ bounding boxes overlapped, not the visible objects themselves, causing some participants to think that two objects visibly overlapped when only their bounding boxes did (see Figure 9), especially when an object overlapped with large text placeholders. The

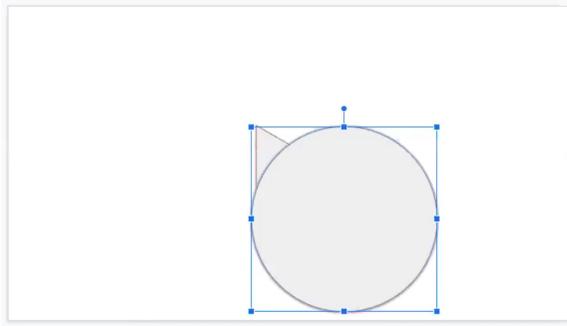


Figure 10: When attempting task #18, which was to move the oval such that it overlapped the triangle, P6 resized the oval to overlap the triangle because he was unsure how to move the shapes.

tasks that involved determining relationships among objects (tasks #5, #11) had some of the lowest success rates (see Figures 3b & 4). For example, half of the participants were able to at least partially determine the rectangle's and oval's positions on the pre-made artboard (see Figure 3a), but only four were able to at least partially determine the relationship between the rectangle and the oval. Reasons for this included the high cognitive load involved in determining position, mental models of spatial relationships announced by the screen reader that were incongruent with the material on the artboard, as well as difficulty in interpreting information from the program.

Several participants assumed that their screen reader announced objects on the artboard from left to right, as it does with text. However, for both Microsoft PowerPoint and Google Slides, absent a template, screen readers announced objects in their vertical Z-order, which would announce the most recently-placed object first. This caused confusion, misinterpretation, and surprise. For example, P2's screen reader announced the objects in the prepared slide for Phase 2 (see Figure 3a) according to their Z-order: "Rectangle obscured. Right arrow. Oval. Text frame, 'Hello, world.'" P2 interpreted this to mean that the arrow was between the rectangle and the oval, and the oval was to the right of the rectangle because it was announced after the rectangle. P13 said that she was not sure of the relationship of the objects, "but normally in PowerPoint, everything is set in the middle and then JAWS just reads it down as a list. So I'm going on that. So I would assume that it's just one underneath each other." P4 said that he and his sighted teammates had also made this assumption when creating storyboards in a presentation meant for blind people, only for him to find when he attempted to screen-read the presentation that the labels for the storyboard images were not read left-to-right and top-to-bottom like text, but instead read in Z-order, making the storyboards nearly impossible to understand.

As noted in the previous section, screen readers announced an object's position on the artboard either in points or inches, which not all participants found useful; P9 commented that she would prefer relative terms like "near the bottom," "to the left," or "center," because, in her words, "what does 500 from the bottom mean?" P7, after listening to a triangle's distance from each slide edge in points,

responded, "Okay, so where's the triangle?" P4, when he determined the width of an object in inches, said that he was not sure how big it was relative to the slide, because he did not know the width of the slide, making the information he was given meaningless. P8 thought that there should be a way to get an overview of a slide's layout before deciding whether he needed to know the precise positions of objects: "When you print something, there's always a print preview, so you, as a visual person, you can see what the page is going to look like before you actually print it. We need something as blind people to have a print preview, but it would just be describing where elements are in relation to one another on the page."

Even when a participant technically had all the information they needed, the cognitive load made remembering all of that information difficult. While attempting to place the triangle in the bottom-left corner of the artboard in task #13, P4 opted to use the position options in a shape-formatting task pane, in which he could enter the desired horizontal and vertical positions in inches (see Figure 11). To do this, he had to calculate what the coordinates for the bottom-left corner would be, and realized he had made a miscalculation along the way: "My thought process was because the triangle was one inch by one inch, so I thought when I put horizontally 0.5 inch from the left and 8.5 inch from the top, then that means because... Oh, I made a mistake. Sorry, no, the *width* of the slide is 10 inch, not the height of it." The coordinates he entered meant that the triangle was placed at the correct horizontal position, but its vertical position was much lower than the artboard itself, which allowed him to place the triangle there without communicating that it was off the artboard.

P9 pointed out, after placing the oval next to the triangle in task #17 (see Figure 7d), that although she had mathematical information about the objects and knew whether or not they overlapped, she "can't even picture what that looks like." She knew they were next to each other but was unsure how close they actually were. She guessed that the oval was below the triangle but clarified that she had "no idea." After listening to her screen-reader output again she thought they were overlapping because the screen reader announced the overlapping bounding boxes as one object "covering" the other. She said she would have to "listen to it a few times, write it down because I can't remember it" in order to determine in what way the objects were overlapping (e.g., whether the oval was overlapping one corner of the triangle or a full side of it).

Participants developed various workarounds for the issue of determining objects' spatial relationships. In the contextual interview, P2 said that when she teaches other blind people how to use PowerPoint, her suggestion for image placement is to add an image and then have a sighted friend "slide the picture around [and] fix it." P1 said that she used preset templates to ensure artboard objects did not overlap each other. P3, P6, and P7 all said that they sometimes used Aira when they needed to check the layout of an artboard. During the task-based usability study, P6 was unsure how to move the oval to overlap the triangle in task #18, so instead he resized the oval until his screen reader announced that the shapes were overlapping (Figure 10).

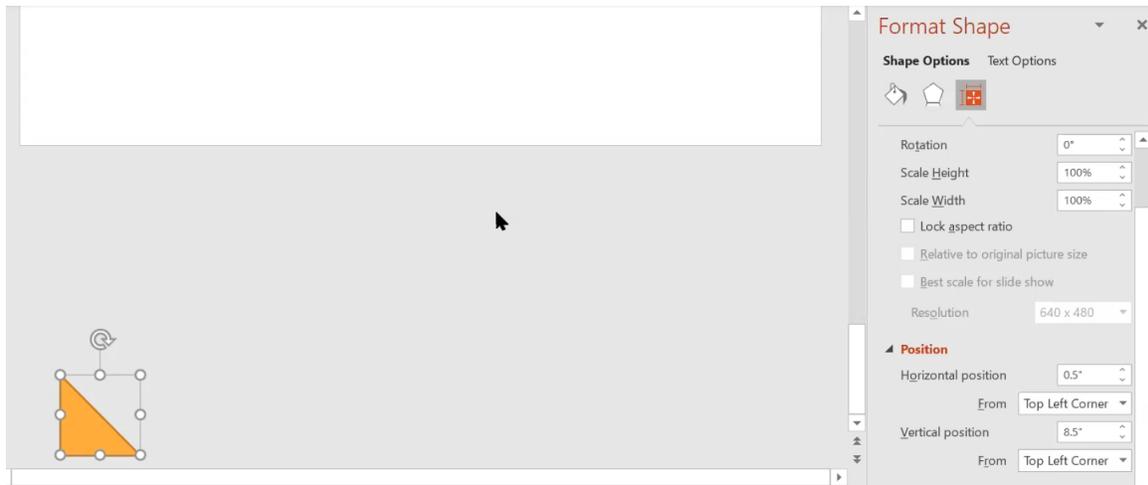


Figure 11: P4 uses the “Format Shape” task pane to input horizontal and vertical positions in inches, which he has calculated for his triangle. However, the triangle is placed much lower than he expected, in fact, off the artboard entirely.

4.5 Uncertainty about Object Manipulation Success

Microsoft PowerPoint and Google Slides gave little-to-no feedback when participants manipulated objects. While participants received feedback about an object’s coordinates while moving one, they typically did not when placing, deleting, rotating, resizing, or changing the color of one. When performing those tasks, participants either had to spend extra time trying to confirm that they had been successful, or would have to guess whether they had completed their task and indicate that they were done. Performing extra steps to confirm success was often irritating or tedious. After resizing an object, P13 commented that she had “no idea” if she was successful. Thus, while participants often were technically successful when manipulating objects, they either were uncertain about their success, or took extra time during the task to confirm that their manipulation had worked. This variance in approaches, as well as participants being less familiar with object manipulation than they were with reading slides, contributed to a greater variance in task durations for tasks that required object manipulation (tasks #12-23; see Figure 6b).

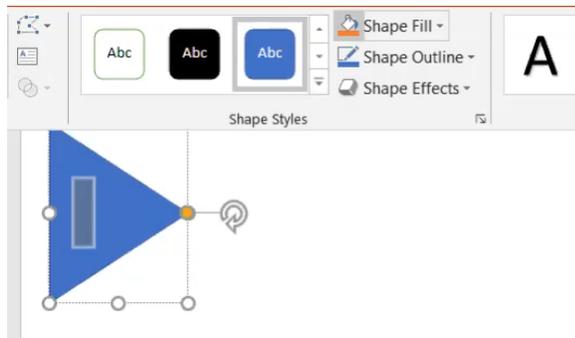
During tasks which involved object manipulation in Phase 2, none of the participants were able to both change the color of a triangle and confirm that the change was successful (task #16), but four participants changed the text color (task #22) and felt confident it had worked; P2 said she already knew how to do that, and the others also might have had prior experience manipulating text attributes.

Six participants were able to confirm that they had rotated an object (task #15) by checking the object’s attributes in the formatting menu. Most participants also felt confident removing an object (task #19), even though there was no immediate feedback, because they could confirm it had been removed by cycling through the objects remaining on the artboard. Of the 10 participants who successfully

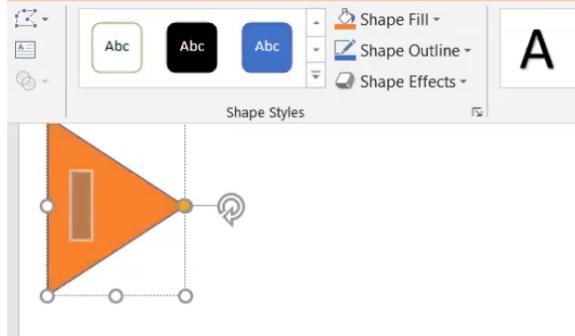
removed the triangle, 8 of them found a way to confirm that they had succeeded.

While participants received clear feedback when objects overlapped each other, it was more difficult to tell when two objects were adjacent but not touching. Two participants fully succeeded and six participants partially succeeded with task #17, which was to move the oval so it was next to the triangle. P4, who used the Format Shape task pane to position his shapes, first calculated what the oval’s horizontal and vertical position should be in order to be close to the triangle without overlapping it: “I have to remember some math and if I refer to my memory, I put [the triangle] horizontally five, I think 4.5, from top and 0.5 from the left and we doubled the size so it would [be] 2.5 inches from the left. So if I put my oval in a position like 2.5 from the left and 4.5 from the top [...] all right.” After placing the oval, he confirmed both shapes’ positions by rereading their coordinates in the Format Shape task pane.

4.5.1 Concerns over “Fragility”. Occasionally, when participants would accidentally manipulate an object, the lack of feedback meant that they either did not realize the manipulation had happened, or only realized it belatedly. Participants also brought this up during interviews, noting that they were sometimes afraid or nervous about navigating their screen reader through a slide because they could unknowingly make changes. We refer to this as a perception of “fragility”: the user’s perception that an artboard’s state is easily breakable, causing users to be afraid to interact. P9 commented that she was “afraid that if I arrow around too much it’ll change the position of my slide, which I can’t fix easily,” echoing P3 who said that she was worried about “messing up” the format of collaborative presentations in her work. Meanwhile, P4 expressed fear that he could unintentionally move placeholders on the artboard, which might make his presentations look unprofessional. This uncertainty was one of the reasons that participants said they would have sighted helpers check presentations they made. For instance, P3 said she would either ask a co-worker or use Aira and P4 said that



(a) P2 locates the Shape Fill button, which is actually two buttons: the left one fills the selected shape with a default color and the right one opens a dropdown menu with more colors.



(b) The artboard's state after P2 clicked the button, which filled her triangle with the default color (orange) without announcing the change, and switched focus from the menu back to her triangle.



(c) The artboard's state after P2 changed the artboard red. A key command she tried silently switched focus to the artboard and opened a "Format Background" task pane, which she used to change the color of the artboard's background, leaving her with an orange triangle and a red artboard.

Figure 12: P2's artboard state as she attempts to change the color of the triangle in the upper left corner from blue to red, without any feedback indicating the color changes were successful or what objects the changes were applied to.

he would "never dare present my PowerPoint presentation" without someone sighted looking at it first.

Accidental manipulations occurred several times during the task-based usability study due to the lack of feedback both for manipulations and object focus, as screen readers did not always announce when the keyboard focus changed from one object to another, or

the announcement was nested in a long string of announcements and was missed by the user. For example, when P2 attempted to change the color of the triangle in task #16 (referenced in Figure 1 and Figure 12), she selected the "Shape Fill" button, which fills the selected shape with a default color or can be opened as a dropdown menu to choose more colors (see Figure 12a). When she clicked the button, it filled her triangle with the default color (orange) without announcing the change, and switched focus from the menu back to her triangle (see Figure 12b). P2 was confused and navigated back to the Shape Fill button and clicked it again, and it switched focus back to her triangle once more, prompting her to voice confusion and frustration: "What? Why won't it do ... It won't let me get into ...". She tried a key command, which silently switched focus to the artboard and opened a "Format Background" task pane with a dropdown fill button, which she used to select a shade of red that was applied to the artboard, leaving her with an orange triangle and a red artboard (see Figure 12c). After reading through the other formatting options in the task pane and noticing they referred to the "background," she switched keyboard focus and found that it switched to the triangle, which she had thought she already had focus on. At that point, she decided to end the task, saying, "Uh, I tried. Did not know if it worked, or if I made the whole slide red. [laughs] I did what I could, I don't know what else I can do."

4.6 Issues Specific to Microsoft PowerPoint

Our study also uncovered several usability problems specific to the programs used, particularly with Microsoft PowerPoint, as that was the program most participants were familiar with. While our focus was on the artboard as an interface separate from the application user interface in which it was contained, we observed several accessibility issues specific to PowerPoint. Every participant who used PowerPoint struggled to navigate the ribbon menu, which often required the participant to know the location of an item they needed in order to find it, which made it extremely difficult to discover the options available. Navigating the menu with a keyboard meant that buttons that could only be reached with the up or down arrows, instead of tab or left/right, were skipped unless the participant knew in advance that the button was not in the linear keyboard navigation path. Additionally, the task pane participants entered when formatting shapes was difficult to re-enter once participants had changed the keyboard's focus; until one participant discovered a keystroke command to re-enter the task pane, participants could only access the shape formatting options in the ribbon menu or by opening a new presentation.

5 DISCUSSION

Our results make it clear that artboards broadly—and digital presentation programs specifically—present unique challenges for blind users. While participants were technically able to complete most of the tasks in Phase 2, the task-based usability test, the levels of energy and concentration it took to complete them was not something most considered worthwhile if they were working on a presentation outside of the study, especially when they would still have to request sighted assistance to confirm that they succeeded in what they attempted to do.

It is interesting to note that most of the tasks could be completed successfully by especially savvy users, but nonetheless required tedious operations that often required exacting precision and, as P4 put it, “an elephant memory.” While completing the tasks, many participants quickly generated design ideas for features they would want in order to perform that task: some solutions were relatively simple, such as adding or modifying the feedback they received; several others were inspired by existing software like Apple iOS VoiceOver. This feedback indicates the need to improve artboard interactions, and further emphasizes that blind screen-reader users are experts on their own access needs, making them necessary collaborators for more accessible solutions.

Success rates for the different tasks varied greatly between participants. Due to the small sample size, there were not many clear patterns in participants’ performance, except that, as might be expected, younger participants were generally more likely to have higher success rates, although there were multiple outliers. Participants tended to have marginally higher success rates with the generative tasks (#12-23) over the interpretive tasks (#1-11). Several of the interpretive tasks, such as #2 (identify the rectangle’s color) and #8 (determine the direction of the arrow) were more dependent on the type of screen reader being used and the user’s knowledge of those screen readers’ special features.

Our participants also made clear that blind people desire more autonomy when using creativity tools like digital presentation programs. Many participants expressed frustration that they needed to have sighted assistance with tasks that they felt they should be able to do on their own. The various disconnects participants experienced due to digital presentation inaccessibility creates an “assistance bubble” [34] that can be a barrier for inclusion in professional and educational spaces, and negatively affected participants’ confidence and perceived self-efficacy [3].

Participants emphasized that accessibility is not achieved merely by providing “accessibility options” like ALT text, but also through other people, particularly sighted people, (1) knowing that those options are available, (2) having a more accurate mental model of how those options make a project more accessible, and (3) having an understanding of why using these options is important. For instance, participants reported that presentation authors often did not understand how a screen reader interacts with content, and often did not realize that they could add ALT text or how to write good ALT text when they did. At first glance, this may appear to be an issue with these specific presenters failing to use their software to its full extent, but we argue that the design of the programs themselves might make these failures less likely; below, we suggest design interventions to achieve this.

5.1 Design Recommendations

Based on participant interviews and observations, we identify three goals for design interventions that, if achieved, would improve artboard accessibility for blind people. We emphasize that any design interventions should consider Lundgard et al.’s [33] sociotechnical considerations for non-visual design, especially by working with blind stakeholders during the design process. The following ideas

have not yet been prototyped, but are ideas that arise from participants and their experiences, as well as prior work, and are described to foster creative brainstorming.

5.1.1 Accessibility Features. Using Bennett et al.’s [5] interdependence frame, we recognize the significant and unreasonable effort that blind people put into achieving access for themselves, from the various workarounds employed to requesting sighted assistance from colleagues, friends, or family. The accessibility of artboards can be understood as a relation between a blind person and the artboard program, other assistive technology like screen readers and Braille displays, and the other people who interact with the blind person and the artboard project: a colleague they are collaborating with, a teacher who authored the project, or the intended recipients of the artboard project the blind person is authoring. Disability and accessibility are created and maintained through all of these relationships.

What kinds of accessibility features could assist a sighted user authoring an artboard project for an audience that includes one or more blind screen-reader users? While some programs like Microsoft PowerPoint now make ALT text options more visible, several participants talked about experiences with colleagues or teachers who still did not make presentations accessible, even though they knew that the participant was in their audience. P1 expressed a desire for presentation programs to alert an author when their presentation is inaccessible, “so they would have to knowingly exclude people in order to not have the accessible [presentation].” Other features may include brief descriptions of how a screen reader works when the ALT text pane is opened, and explanations of other ways a presentation may be inaccessible besides a lack of ALT text.

5.1.2 Glanceability. Several participants expressed that the cognitive load required to understand a slide’s spatial layout, or to accomplish other tasks related to that, was not worth the results they achieved. However, participants indicated that this information would be useful to have if it did not require as much effort and expertise to obtain it. P9, for example, said that she would prefer to know an object’s position in relative terms like “near the bottom” instead of receiving a more precise measurement, because that required her to make mental calculations to understand an object’s location. P8 said that, just as sighted users receive a print preview of a document, “we need something as blind people to have a print preview, but it would just be describing where elements are in relation to one another on the page.”

A “print preview” could, for example, use 3-D spatialized audio as it announces artboard objects, giving the user a general understanding of the artboard’s layout by hearing which quadrant of the artboard an object is in: closer to the top or the bottom, closer to the left or the right, or close to the center of either axis. Spatial information that is deemed to be most relevant, such as object size, color, and overlap could also be communicated as objects are announced. Not all of this information needs to be communicated through speech, as prior research has found that non-speech audio lowers the user’s perceived cognitive load (e.g., [14]). For example, a property like an object’s size could be mapped to pitch.

P7 proposed tactile feedback as an option for improving glanceability: “I want to visualize the triangle as I’m like feeling with my fingers [...] and resizing it to make it bigger or larger, or more,

whatever.” P1 also suggested this, saying: “if you had the PowerPoint on the phone as well, it would be good if you could feel more easily like on the screen to know where different things were, like where you could move your finger on the screen on the phone.” For example, like EdgeSonic [56], a user could slide their finger across a touchscreen, and hear sonification when their finger encounters an object’s edge; or, they could hear object callouts as they slide their finger across the screen, like they would using VoiceOver on an iPhone. Like P1’s idea, and also demonstrated by Potluri et al. [43], another device like a phone or tablet could be used in tandem with a desktop so a user could navigate the artboard via touch, but could still make finer edits on their desktop.

Lessening the cognitive load may also necessitate prioritizing the set of features most suitable for the user’s current task (e.g., changing the background color, inserting an image, or rearranging text boxes), so that those features are readily available for the user as opposed to being tucked into a more complex menu system, following the usability criteria set forth in DIN ISO 9241:110 [25].

Better glanceability would also be effective for determining relationships among artboard objects. Participants reported being misled by the order their screen readers announce objects on the canvas, in Z-order instead of left-to-right and top-to-bottom like they had expected. Imagine a feature that allows a user to choose the order in which objects are read. While a couple of participants expected the order to be from top-to-bottom, most expected objects to be read from left-to-right, so that might be the default order (provided that the default language being used is one that is read from left-to-right).

5.1.3 Robustness. Several participants perceived the artboards in Microsoft PowerPoint and Google Slides as *fragile*, something that they could easily mess up unknowingly, which caused participants to be afraid to interact with projects. Instead, we propose that an artboard should be *robust*, in order for users to perceive it as something they can manipulate without worrying that they will break it. A robust artboard would, for example, clearly indicate to a user that an object manipulation has occurred and describe what that manipulation was. A robust artboard would also allow a user to quickly and easily reverse or undo a recent object manipulation. A user should be able to easily determine which previous version of the project they might wish to return to if several object manipulations need to be reversed. A robust program would also make clear distinctions between keystrokes that are being used to navigate versus keystrokes that are being used to manipulate objects.

One way to add robustness could be to add clear “read” versus “edit” states that could be easily toggled with a hotkey. For example, a user may open an artboard program with the sole purpose of accessing a work they do not intend to edit, so they remain in the “read” state. When a user is editing a project, they can switch to the “edit” state as needed. Or, imagine this feature as part of a multi-device approach like Potluri et al. [43] describe, in which one device (e.g., a phone or tablet) may be in the “read” state while the other device (e.g., a desktop or laptop computer) may be in the “edit” state.

5.2 Limitations

The limitations of this work include that our study of artboard programs centered on the programs participants were most familiar with, which for most participants was Microsoft PowerPoint. We used convenience sampling to recruit participants, which may have affected results. Although our focus was on the 2-D artboard components of digital presentation software, we did find that certain operations, such as color identification, were, in fact, program-specific. We were also limited in our ability to maintain a consistent testing environment for the task-based usability study, as it was necessarily conducted over Zoom due to COVID-19 safety measures.

6 FUTURE WORK

The results of our study suggest opportunities for future work both on digital presentations specifically and on artboard programs more broadly. In addition to addressing the limitations discussed above, future research could evaluate blind users’ interactions with a wider variety of artboard programs and test a wider array of functions within them. In addition, given the proliferation of smartphones and other mobile devices, our research points to an opportunity for evaluating the versions of creativity and productivity tools available on those platforms.

Future work includes developing nonvisual interaction techniques with blind stakeholders and validating them through interactive prototypes, as well as evaluating pixel-based canvases, in order to guide design principles for nonvisual interaction with digital canvases more broadly. It would be very valuable for blind stakeholders to participate in the development of accessibility features that make sighted users aware of the needs of blind people, in keeping with what was suggested by several participants.

Finally, our work suggests that there is much to be gained from qualitative work that studies blind people’s interactions with not only artboard programs or digital canvases, but creativity and productivity tools more widely. Larger or longitudinal interview-based studies might yield richer thematic data, while ethnographies that observe blind people at their workplace or at school might allow researchers to fully comprehend the everyday impact of the access barriers created at the nexus of screen readers and creativity software tools.

7 CONCLUSION

In this work, we conducted a two-part study with blind participants to better understand their experiences and challenges with artboards in digital presentation programs. In the first phase of our study, we conducted interviews and observations of 12 blind people using their preferred artboard program. In the second phase of our study, we conducted task-based usability tests of 12 blind people, with half of our tasks requiring users to interpret existing artboards, and half of our tasks requiring users to generate new artboard designs. We found that the key problems faced were: (1) high cognitive loads from a lack of feedback about artboard contents and state; (2) difficulty determining relationships among artboard objects; and (3) constant uncertainty about whether object manipulations were successful. We offer design remedies that improve feedback for object state, relationships, and manipulations. It is our hope that this work will inform and inspire efforts to make

artboards more accessible in the numerous programs in which they appear, giving all users more agency in the creative expression of their ideas.

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