# Exploring Blind and Low-Vision Youth's Digital Access Needs in School: Toward Accessible Instructional Technologies

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Blind and low-vision (BLV) youth have been excluded from technology-mediated learning in school for two decades due to the systemic inaccessibility of K-12 instructional technologies. Accessibility guidelines that address BLV youth's needs would help schools address this systemic inequity. But such guidelines do not yet exist nor does the robust knowledgebase required to write them. Herein, I report three key findings from a mixed methods user study of BLV youth's lived experiences learning with access technologies (AT) and instructional technologies in US schools. First, these youth participants are using a broader range of AT than youth in previous studies. Second, the youth in this study frequently developed their AT literacy outside of school, and most did not begin developing AT literacy in earnest until they were teens. Third, the youth defined accessible instructional technologies as those that are (1) easy to learn to use and (2) easy to use to learn and they used an inquiry process to evaluate accessibility. Building on the findings, I offer six preliminary design guidelines for accessible instructional technologies. Finally, I urge other scholars to study BLV youth's digital access needs so that standards setting bodies eventually have sufficient data to write youth accessibility guidelines.

CCS Concepts: • **Human-centered computing** → **Empirical studies in accessibility**;

Additional Key Words and Phrases: Blind and Low-Vision, Children, Instructional Technology, K-12, Access Technology (AT), Screen Reader, Refreshable Braille Display

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## 1 Introduction

**Blind and low-vision (BLV)** youth[1] have been excluded from technology-mediated learning in school for two decades due to the systemic inaccessibility of K-12 instructional technologies[2] [Shaheen, 2022a, 2022b; Stefik et al., 2019]. The absence of nationally recognized and legally

[1]The term BLV youth refers to students who qualify for special education services under the "visual impairment" category of the Individuals with Disabilities Education Act. See Section 3.4 for an explanation of why I use the term BLV instead of "visually impaired."
[2]Herein, I use the term instructional technology to refer to digital technologies that are intentionally used for teaching and learning purposes [Ely, 2008].

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enforceable accessibility guidelines that address the needs of BLV youth exacerbates this problem. Developing such guidelines requires deeper knowledge of BLV youth's digital access needs than is currently available in the literature [Accessibility for Children Community Group, 2022; J. Spellman, personal communication, June 25, 2020]. Accordingly, I conducted a mixed methods user study with 16 BLV youth to understand their lived experiences learning with technology in school.

In the United States, most BLV youth attend public K-12 schools [U.S. Department of Education, 2022] where their peers and teachers are sighted [Torres and Durando, 2011]. In these schools, sighted ways of learning and interacting with technology are hegemonic [Shaheen, 2023]. The sighted hegemony in K-12 excludes BLV youth from technology-mediated learning in two primary ways. First, BLV youth's technology literacy is often artificially confined because their sighted teachers rarely know how to use nonvisual **access technology (AT)**,[3] such as screen readers [Ajuwon et al., 2016; Zhou et al., 2011; Zhou et al., 2012]. Second, most of the instructional technologies used in K-12 are inaccessible, in part because educators lack knowledge about accessibility [Shaheen, 2022b]. To access technology-mediated learning, BLV youth need both AT and accessible instructional technologies; neither technology is sufficient alone.

Historically, accessibility has not been part of K-12 instructional technology discourse and practice [Shaheen and Lohnes Watulak, 2019]. However, legal actions taken against K-12 schools [e.g., Bartleson v. Miami-Dade County School Board, 2018; Berkley Unified School District and Sun, 2022; Nightingale v. Seattle School District, 2014; Office for Civil Rights, 2023] coupled with recent state policies (e.g., Illinois Public Act 102-0238; Maryland Equivalent and Nonvisual Access Accountability Act for K-12 Education; Texas Education Agency Proclamation 2024) are prompting a slow shift toward incorporating accessibility into instructional technology practice in K-12, particularly during procurement. For example, Illinois Public Act 102-0238 requires school districts to ensure their online curriculums and web services are compliant with **Web Content Accessibility Guidelines (WCAG)** 2.1 AA. Similarly, Texas Education Agency Proclamation 2024 requires education publishers, who want to sell their instructional technologies to local schools, to furnish a third party accessibility evaluation that demonstrates compliance with WCAG 2.1 AA and Section 508. Currently, most state and school district policies use WCAG [Campbell et al., 2023] and/or Section 508 as the benchmark for evaluating accessibility, a logical policy choice given legal precedents.

However, WCAG and Section 508 do not address the needs of youth users. Though WCAG does not explicitly identify relevant user age groups, the guidelines allude to adults and specifically mention "older individuals" [Campbell et al., 2023, Background para 1]. However, WCAG never uses the terms *youth*, *children*, or *younger individuals*. Moreover, a **World Wide Web Consortium (W3C)** Community Group, Accessibility for Children (www.w3.org/community/accessibility4children), was established in 2019 to raise awareness about and address this shortcoming in future iterations of WCAG. To that end, the Accessibility for Children Community Group has developed documentation about why youth accessibility guidelines are necessary [see Taylor and Stiernet, 2022; Accessibility for Children Community Group, 2022].

Evaluating youth-focused instructional technologies against adult-focused accessibility guidelines is substantially better than ignoring accessibility. But this practice is not ideal. Youth needs (irrespective of disability) differ from adult needs because humans' developmental profiles (e.g., cognitive, social, fine motor) shift as they age [Accessibility for Children Community Group, 2022; Hourcade, 2008]. Furthermore, many BLV adults are adventitiously blind and adventitious blindness has a different impact on concept and skill development than congenital blindness [Kaiser et al.,

[3]Herein, I use the term *access technology*, as opposed to *assistive technology*. This choice is grounded in both the preference of the blind community and corresponding shifts to the terminology educators use [Siu and Presley, 2020].

2018]. To ensure the instructional technologies that K-12 schools use are accessible to their BLV students, schools need youth accessibility guidelines. Currently, the literature does not contain sufficient data for standards setting bodies, such as the W3C, to write youth accessibility guidelines [J. Spellman, personal communication, June 25, 2020].

Recently, scholars in both **human-computer interaction (HCI)** and education have called for more research exploring BLV and other disabled youth's experiences using technology in school [Gadiraju et al., 2021; Huff et al., 2021; Klingenberg et al., 2020; Tomlinson et al., 2020]. Gadiraju et al. [2021] specifically requested interview studies with blind youth. This paper answers those calls. Moreover, this work, along with research conducted by members of the Inclusive Educational Technology initiative [Brulé et al., 2019; Metatla et al., 2018], moves the literature incrementally closer to the robust knowledgebase required to write youth accessibility guidelines and develop instructional technologies that are accessible to BLV youth.

This paper makes four key contributions. First, the paper furnishes data about the AT BLV youth are using in school today. Second, the paper provides data about how and when BLV youth learn to use AT. Third, the paper shares insight from BLV youth about how they differentiate between accessible and inaccessible instructional technologies. Finally, the paper offers six design guidelines for accessible instructional technologies that are grounded in BLV youth's experiences using technology in school.

## 2 Related Work

A broad review of the HCI, education, and legal literatures reveals important insight about AT literacy and use in school, the systemic use of inaccessible instructional technologies in K-12, and developing accessible instructional technologies. The literature also offers a small corpus of research conducted with BLV youth participants to understand the youth's interactions with technology.

### 2.1 AT Literacy and Use in School

Most BLV youth are raised by sighted elders, consequently their families rely heavily on schools to teach them nonvisual ways of learning and living such as Braille, using a white cane, and AT. Unfortunately, the literature indicates that educators often lack AT knowledge [Davis et al., 2013]. In the United States, even the **teachers of blind students (TBSs)**, who are licensed to teach BLV children are not confident in their knowledge about BLV AT [Ajuwon et al., 2016; Zhou et al., 2011; Zhou et al., 2012]. TBSs are least confident in their knowledge of nonvisual AT (i.e., Braille displays and screen readers) [Zhou et al., 2012]. Disappointed by the findings of their study, Zhou et al. [2011] characterized the state of TBSs' AT knowledge as "dismal" (p. 205). Historically, TBSs' lack of AT knowledge has negatively impacted BLV youth's use of technology [Zhou et al., 2012].

The education literature reveals that upwards of 60% of BLV youth are not using AT [Kapperman et al., 2002; Kelly, 2009, 2011]. For example, Kelly [2011] found that in the United States only 42% of BLV high school students were using AT and students attending schools for the blind were 1.8 times more likely to use AT than their public school peers. In alignment with AT usage data, Kelly and Wolffe [2012] found that only 43% of BLV students were using the internet at a time when 93% of their non-disabled peers were online.

Recent literature in HCI has also indicated low AT literacy levels among BLV youth. Kane et al. [2018] found that several of the teen participants in their sample of nine had little knowledge of screen readers or computers, which impeded their learning in a computer science program. Moreover, eight of the teacher participants ($n$ = 12) in Mountapmbeme and Ludi's [2021] study reported that BLV youth's limited computer and screen reader skills posed a barrier when the youth were learning to code using block-based languages.

The literature reveals that most BLV youth are nowhere near AT literate. Most youth have not even had meaningful opportunities to use AT. Teachers' lack of AT knowledge is likely a contributing factor to the youth's limited access to AT.

### 2.2 Systemic Inaccessibility of K-12 Instructional Technologies

The BLV youth who have developed some AT literacy remain excluded from much of the technology-mediated learning in K-12 due to the systemic inaccessibility of instructional technologies.

A plethora of legal actions taken against K-12 schools in the United States since 2014 have uncovered that the use of inaccessible instructional technologies is a systemic problem. Over 2,000 Office for Civil Rights complaints have been filed against school districts around the United States since 2016 due to their websites' incompliance with WCAG [Keierleber, 2018]. Additionally, two school districts have faced lawsuits because they were using inaccessible instructional technologies [Bartleson v. Miami-Dade County School Board, 2018; Nightingale v. Seattle School District, 2014]. The lawsuit against Seattle School District identified two inaccessible instructional technologies: ST Math and the school's website. Miami-Dade County Public Schools was using three types of inaccessible technologies according to the lawsuit: websites, web forms, and software applications.

Alarmingly, the use of inaccessible instructional technologies increased dramatically during the pandemic excluding BLV youth from even more learning [Huck and Zhang, 2021; Shaheen, 2022a]. In an open letter to education officials around the United States [Riccobono, 2020b], the president of the **National Federation of the Blind (NFB)**, outlined the ways inaccessible instructional technologies were harming BLV youth and implored officials to take swift action to rectify the injustice. Riccobono [2020] wrote "blind students cannot access their instruction, complete and submit their homework, participate in virtual class discussions, complete pop quizzes and tests, or check their grades." (para 3). He pointed to Seesaw and Epic! as examples of popular K-12 instructional technologies that are inaccessible.

### 2.3 Developing Accessible Instructional Technologies

To combat the systemic inaccessibility of instructional technologies, HCI scholars have developed instructional technologies for BLV students in K-12 and higher education.

The field has devoted substantial effort to developing technologies for nonvisual computer science education [Kane et al., 2018; Koushik et al., 2019; Ludi, 2015; Ludi et al., 2014; Ludi and Spencer, 2017; Morrison et al., 2020; Mountapmbeme et al., 2022; Mountapmbeme and Ludi, 2021; Stefik et al., 2019; Van Der Meulen et al., 2022]. Within this body of work, some projects have developed accessible programing languages. Stefik et al. [2019] developed Quorum, an evidence-based programing language designed to be accessible to BLV people and Morrison et al. [2020] developed a tangible programing language, Torino, for BLV youth age 7–11. Besides new programing languages, scholars have developed accessible programing environments and programing workflows. Kane et al. [2018] developed an accessible programing environment, Bonk, to allow novice BLV programmers to create audio games. Ludi and Spencer [2017] developed an accessible programing workflow for Blockly, which did not require the use of a mouse.

HCI Scholars' development efforts have extended beyond computer science education. Researchers have also developed instructional technologies for science [Sánchez and Aguayo 2008; Sánchez and Flores, 2008; Tomlinson et al., 2020], math [McGookin et al., 2010; Moll and Pysander, 2013; Ohshiro et al., 2021; Sánchez, 2008], English/language arts [Ahmetovic et al., 2023; Gadiraju et al., 2020; Milne et al., 2014], and the expanded core curriculum [Gadiraju et al., 2021; Sánchez, 2008; Sánchez et al., 2010]. For example, Tomlinson et al. [2020] used sonification (i.e., non-speech audio) and dynamic descriptive audio to make accessible high school science simulations. Two other teams developed Braille literacy games. Milne et al. [2014] created BraillePlay, a suite of four smartphone games using touch screen input. Gadiraju's [2020] team combined a computer, a web cam, and tangible blocks to create BrailleBlocks, a game for BLV youth and their parents.

Most efforts have focused on developing instructional technologies specifically for BLV students. But some scholars have set out to develop instructional technologies that encourage BLV and sighted people to learn and play together [Ahmetovic et al., 2023; Metatla et al., 2020; Moll and Pysander, 2013; Morrison et al., 2020; Sánchez and Aguayo, 2008; Stefik et al., 2019; Tomlinson et al., 2020]. For example, WorldMelodies [Ahmetovic et al., 2023] is a bilingual (English and Italian) literacy app that includes 80 plus exercises. Metatla et al. [2020] developed an educational game using off-the-shelf robots to foster inclusive play among youth ages 9–10.

The instructional technologies that HCI scholars have developed demonstrate many novel approaches to nonvisual digital learning including sonification [Lahav et al., 2016; Ohshiro et al., 2021; Tomlinson et al., 2020], tangible user interfaces [McGookin et al., 2010], haptic or kinetic output [Guinness et al., 2018; Muehlbradt et al., 2018], olfactory output [Brulé et al., 2016], and using technology to enhance the usability of analog tactile graphics [Suzuki et al., 2017]. For example, the Haptic Video Player [Guinness et al., 2018] used a mobile robot to provide nonvisual access to spatial information in educational videos; when a circle was drawn on screen the BLV person could feel the robot draw a circle in real-time. FluxMaker [Suzuki et al., 2017] employed magnetic dynamic tactile markers to annotate analog tactile graphics, providing an additional layer of nonvisual spatial information to BLV users.

### 2.4 Research with BLV Youth Participants

To date, the HCI literature pertaining to BLV people's interactions with technology has focused primarily on adults. A recent review of quantitative HCI studies ($n = 243$) found that the median age of BLV participants was 37 with an age range of 9–80 (Brulé et al., 2020). A search of Google Scholar and the ACM Digital Library surfaced 14 studies that had BLV youth participants, investigated BLV youth's interactions with technology, and were published in HCI outlets. Most ($n = 8$) of the HCI studies were conducted by researchers involved in the Inclusive Education Technologies initiative (http://www.inclusiveeducation.tech/) [Brulé et al., 2019; Metatla et al., 2018], which demonstrates the impact the initiative has had on advancing the knowledgebase. Three additional studies were available in the education literature. See Table 1 for a complete list of the studies.

The 17 studies were published between 2004 and 2023. 47% ($n = 8$) of the studies were published in the last five years. Most of the studies were conducted with youth outside of the United States ($n = 11$) and primary-school-aged youth (5–11 years old) ($n = 9$). Only four studies specifically targeted secondary-school-aged youth (12–22 years old). The small corpus primarily focused on developing novel instructional technologies that BLV youth would enjoy and find useful. For example, WorldMelodies [Ahmetovic et al., 2023] and BrailleBlocks [Gadiraju et al., 2020], which were discussed above.

Only five of the 17 studies focused on understanding BLV youth's experiences learning in school with existing instructional technologies. Two studies were conducted in the United States and three were conducted in Western Europe.

In the United States, Kamei-Hannan [2008] observed BLV youth aged 7–21 take a standardized test at a school for the blind and found two significant access barriers: (1) poorly coded text passages that prevented nonvisual scrolling and (2) pictures without alternative text. [D'Andrea, 2012] interviewed 12 American youth aged 16–20 who were Braille readers and AT users. D'Andrea found that the youth used very few instructional technologies (i.e., wikis, Google Docs, blogs) besides PowerPoint.

In Europe, Brulé et al. [2016] observed 13 youth aged 7–19 at a school for the blind in France to understand the youth's experiences with technology. They identified three needs: (1) children

Table 1. Studies with BLV Youth Participants

| Author(s) | Year | Field | Country | Age Group[a] | Number of BLV Youth | Focus of the Study | Inclusive Ed Tech Initiative |
|---|---|---|---|---|---|---|---|
| McElligott and Van Leeuwen | 2004 | HCI | UK | Primary | 5 | Developing novel instructional technologies | |
| Kamei-Hannan, | 2008 | Education | USA | Primary-Secondary | 49 | Youth's experience learning with existing instructional technologies | |
| Sánchez | 2008 | HCI | Chile | Primary-Secondary | 37 | Developing novel instructional technologies | |
| Sánchez et al. | 2010 | HCI | Chile | Primary-Secondary | 20 | Developing novel instructional technologies | |
| Song et al. | 2011 | Education | Malaysia | Secondary | 25 | Developing novel instructional technologies | |
| D'Andrea | 2012 | Education | USA | Secondary | 12 | Youth's experience learning with existing instructional technologies | |
| Moll and Pysander | 2013 | HCI | Sweden | Primary | 4 | Developing novel instructional technologies | |
| Milne et al. | 2014 | HCI | USA | Primary | 8 | Developing novel instructional technologies | ✓ |
| Brulé et al. | 2016 | HCI | France | Primary-Secondary | 13 | Youth's experience learning with existing instructional technologies | ✓ |
| Brulé and Bailly | 2018 | HCI | France | Primary | 5 | Youth's experience learning with existing instructional technologies | ✓ |
| Kane et al. | 2018 | HCI | USA | Secondary | 10 | Developing novel instructional technologies | ✓ |
| Metatla and Cullen | 2018 | HCI | UK | Primary | 6 | Youth's experience learning with existing instructional technologies | ✓ |
| Koushik et al. | 2019 | HCI | USA | Secondary | 5 | Developing novel instructional technologies | ✓ |
| Gadiraju et al. | 2020 | HCI | USA | Primary | 6 | Developing novel instructional technologies | ✓ |
| Metatla et al. | 2020 | HCI | UK | Primary | 8 | Developing novel instructional technologies | ✓ |
| Morrison et al. | 2020 | HCI | UK | Primary | 4 | Developing novel instructional technologies | |
| Ahmetovic et al. | 2023 | HCI | Italy | Primary | 11 | Developing novel instructional technologies | |

[a]Age Group : Primary-school-aged youth are 5–11 years old. Secondary-school-aged youth are 12–22 years old. In the United States, disabled youth can remain in secondary school until age 22.

need empowering tools to access maps, (2) educators need to be able to easily create accessible instructional materials, and (3) there needs to be more collaboration among children and between children and educators. Also in France, Brulé and Bailly [2018] conducted a field study in geography classes at a school for the blind and found that the sighted hegemony of geography instruction led teachers to use instructional technologies to support their visual ways of learning rather than to support the youth's nonvisual ways of learning (e.g., auditory, tactile). Finally, in the United Kingdom, Metatla and Cullen [2018] observed six youth aged 7–16 in general education settings and found that sighted paraprofessionals were enlisted as workarounds for inaccessible instructional technologies—an approach that segregated BLV youth from their sighted peers.

Together these studies indicate that BLV youth, on both sides of the Atlantic, have limited access to the instructional technologies that are used in their classrooms.

### 2.5 Gaps in the Literature

While there is a significant body of literature pertaining to nondisabled youth's interactions with technology [Giannakos et al., 2022] and a growing body of research to understand disabled youth's interactions with technology [Börjesson et al., 2015; Guha et al., 2008; Stefanidi et al., 2022], research that employs BLV youth as participants or co-researchers and investigates their interactions with technology is limited [Brulé et al., 2016; Mountapmbeme and Ludi, 2021]. The small corpus focuses on developing novel instructional technologies for primary-school-aged youth outside of the United States Additionally, research about BLV youth's AT use is over a decade old. To begin to address the gaps in the literature and provide data to inform the future development of youth accessibility guidelines, I conducted a study to learn from 22 secondary-school-aged BLV youth what it is like to use both AT and instructional technology in school in the United States.

## 3 Methedology

The data and findings reported herein are part of a transformative convergent mixed methods study (QUAL + quant) [Creswell and Plano Clark, 2018] to understand BLV youth's experiences in technology-mediated formal learning environments (i.e., secondary and tertiary education). "Transformative mixed methodologies provide a mechanism for addressing the complexities of research in culturally complex settings that can provide a basis for social change" [Mertens, 2007, p. 212]. Several philosophical assumptions underpin the transformative paradigm: (1) reality is multiple and socially constructed, (2) an individual's reality is shaped by many factors, including social, cultural, political, and economic forces, and (3) power and privilege should be central considerations when determining which reality to privilege in research [Mertens, 2007].

Following from the philosophical assumptions of the transformative paradigm, I chose to privilege the perspectives of BLV youth, not their teachers or guardians. Consequently, the data I collected for this study came from BLV youth, not proxies. Moreover, the study focused on BLV youth's definitions, not a priori definitions developed by adults, and the meaning BLV youth made of their experiences. For example, with research question 3, I explored how the youth distinguished between accessible and inaccessible technologies, rather than evaluating the technologies through the lens of existing accessibility guidelines. Finally, I chose to prioritize qualitative methods in this study because qualitative methods (1) facilitated dialogue between the participants and me and (2) furnished the rich data required to understand the social and historical contexts in which the youth developed the knowledge they chose to share [Mertens, 2012].

This article focuses on the data pertaining to the youth's interaction with technology in school and development of AT literacy. Three research questions guided this portion of the study.

(1) What AT do BLV youth use at school?
(2) How do BLV youth develop AT literacy?
(3) How do BLV youth differentiate between accessible and inaccessible instructional technologies?

Due to space constraints, I am disseminating findings from the study that pertain to other research questions in separate publications, a recognized dissemination approach for mixed methods research [Creswell and Plano Clark, 2018; Stange et al., 2006]. For example, Shaheen [2024] zooms out from the technology to report the findings about the educational environment in which the technology discussed herein is embedded, data that is most relevant to educators.

This study was reviewed and approved by the Illinois State University IRB prior to commencement.

### 3.1 Sampling

I chose to use two sampling strategies to combat both (1) the "sample size issue" [Lazar et al., 2017, p. 505], which is common in HCI research with disabled people and (2) the complexities of recruiting youth participants during a global pandemic.

*3.1.1 Sampling in the Qualitative Phase.* For the qualitative phase, I used purposeful sampling to identify BLV youth who had significant experience interacting with technology in school. To be eligible to participate in the qualitative phase, BLV youth had to meet six inclusion criteria:

(1) 13–22 years old[4]
(2) Legally blind
(3) Enrolled in formal education (secondary or tertiary education) where technology is used within the last 24 months
(4) Primary learning medium is tactile (i.e., Braille) or auditory (i.e., screen reader, human reader, recorded audio)
(5) Completing academic work (e.g., math, English/language arts) no more than two grade levels below their age-appropriate grade
(6) Use AT (i.e., screen reader, **refreshable Braille display (RBD)**).

I recruited youth participants by circulating email and Twitter solicitations within the blind community, the parent community, and the TBS community. Interested individuals (or their guardians) completed a brief screening survey to determine eligibility. Of the 35 youth who completed the screening tool (or had a guardian complete it for them), 16 met the inclusion criteria and were willing to participate.

In addition to interviewing the 16 qualifying youth, I invited them to share artifacts related to the experiences they discussed in the interview. To be included in the sample, artifacts had to: (1) be shared by a participant and (2) directly pertain to the participant's experiences with technology in formal learning environments.

All youth aged 18 and older completed a consent form. The guardians of all youth aged 13–17 completed consent forms and the youth provided verbal assent prior to data collection. All details about the study from purpose to dissemination plans were shared with the youth and their guardians in accessible mediums, no details were obscured. The youth were also told they could discontinue their participation at any time and could skip any questions they preferred not to answer.

*3.1.2 Sampling in the Quantitative Phase.* For the quantitative phase, I used convenience sampling. At the time I was designing this study, the NFB had been conducting a survey of BLV students' experiences with inaccessible, and to a lesser extent accessible, instructional technologies for approximately 18 months. The NFB developed the survey to inform their programing, not to conduct research. The NFB graciously shared the deidentified data from the survey.

To be eligible to participate in the quantitative phase, survey participants had to meet four inclusion criteria:

[4]Note: BLV youth can remain in secondary school until age 22 in the United States.

(1) 13–22 years old
(2) Legally blind
(3) Enrolled in formal education (secondary or tertiary education) where technology is used within the last 24 months
(4) Use AT (i.e., screen reader, RBD).

The NFB recruited participants through a wide-variety of synchronous and asynchronous events and communication channels in the blind community. The secondary dataset from NFB contained responses from 70 individuals. Many of the respondents were teachers or guardians responding on behalf of BLV students. As discussed at the beginning of Section 3, I prioritized the perspectives of BLV youth, not their proxies, in this study. Only 6 of the 70 survey respondents were BLV youth who met the inclusion criteria.

### 3.2 Participants

To protect participants' identities, herein I use pseudonyms exclusively.

*3.2.1 Participants in the Qualitative Phase.* I gave participants in the qualitative phase the opportunity to select a pseudonym, and several did so. Additionally, I report some demographics exclusively in the aggregate to decrease the likelihood that the youth in my small community could be reidentified.

Participants ranged in age from 13 to 21, and the majority ($n = 12$) were congenitally blind. One notable outlier in the sample was a participant who had only been blind for four years. When asked an open-ended question about how they identified with respect to their vision loss, the majority of participants ($n = 11$) said they identified as blind, and five participants said they identified as both BLV or visually impaired, using the terms interchangeably. As is often the case in the blind community, the disability labels the participants used did not correlate to their level of blindness. For example, some participants who had residual vision identified as blind. With respect to race, the participants identified as white ($n = 10$), Hispanic or Latinx ($n = 2$), Asian ($n = 3$), and mixed race ($n = 1$).

Most of the students were nearing or at the end of secondary school. The 16 participants attended 15 schools in 11 states across the Midwest, Mid-Atlantic, Northeast, South, and West Coast. See Table 2 for additional participant details.

All of the participants were Braille readers and used a combination of mediums to complete their schoolwork (e.g., Braille, audio). For example, audio was Captain Marvel's primary medium for text-based schoolwork, and Braille/tactile was her primary medium for number- and image-based work. Conversely, Braille was Spartan's primary medium for text-based work, and audio was his primary medium for number- and image-based work. Eight students used Braille as their primary medium for all of their schoolwork (i.e., text-, number-, and image-based). Table 3 illustrates how many students used Braille/tactile as their primary or secondary medium for text-, number-, and image-based schoolwork.

*3.2.2 Participants in the Quantitative Phase.* I gave all 70 survey respondents a two-digit ID number. Herein, I use ID numbers as pseudonyms for the six participants who met the inclusion criteria. These impersonal pseudonyms signal both (1) the social distance between the respondents and me and (2) the limited information I had about respondents.

Participants ranged in age from 15 to 21. All six participants responded "yes" to the question *are you blind?* The participants resided in six states. See Table 4 for additional participant details. Unfortunately, the NFB survey did not collect data about participants' gender, race, grade, school, onset of blindness, or when and how they learned to use AT.

Table 2. Select Qualitative Phase Participant Demographics and Descriptive Data

| Pseudonym | Gender | Age | Most Recent Grade Completed | Type of School | Primary AT and IT | Started Learning AT |
|---|---|---|---|---|---|---|
| Alexis | Woman | 13 | 7th | Public Secondary | BrailleNote Touch Plus | 3rd Grade |
| Captain Marvel | Woman | 16 | 10th | Public Secondary | JAWS on Windows laptop | 3rd Grade |
| Ashley | Woman | 16 | 10th | School f/t Blind | VO on iPad | 4th Grade |
| Jacob | Man | 16 | 10th | Public Secondary | BrailleNote Touch Plus | Kinder-garten |
| Juliana | Woman | 18 | 11th | School f/t Blind | VO on iPad | 5th Grade |
| Callie | Woman | 18 | 11th | Public Secondary | BrailleNote Touch and JAWS on Windows Laptop | 4th Grade |
| Jada | Woman | 18 | 12th | Public Secondary | VO on iPhone paired with RBD | 3rd Grade |
| Hannah | Woman | 18 | 12th | Public Secondary | VO on iPad paired with RBD | 8th Grade |
| Sam | Man | 18 | 12th | Public Secondary | JAWS on Windows laptop | 10th Grade |
| Rebecca | Woman | 19 | 12th | Public Secondary | VO on iPad | 3rd Grade |
| Lily | Woman | 19 | 12th | School f/t Blind | BrailleNote Touch Plus | 2nd Grade |
| Spartan | Man | 20 | 12th | Public Secondary | BrailleSense | 6th Grade |
| Rose | Woman | 20 | 12th | Public Secondary | VO on iPhone paired with RBD | 7th Grade |
| Kennedy | Woman | 21 | 2nd yr of univ | Public univ | NVDA on Windows laptop | 7th Grade |
| Fifer | Woman | 21 | 3rd yr of univ | Private univ | JAWS on Windows laptop | 1st Grade |
| Alyssa | Woman | 21 | 4th yr of univ | Public univ | VO and Zoom on Mac | 3rd Grade |

Table 3. Braille/Tactile as a Medium for Schoolwork

| Braille/Tactile Rank | Text-Based Work (e.g., writing essays) | Number-Based Work (e.g., algebra) | Image-Based Work (e.g., reading maps) | All Three Types of Work |
|---|---|---|---|---|
| Primary Medium | 9 | 9 | 12 | 8 |
| Secondary Medium | 5 | 5 | 2 | 2 |

Table 4. Quantitative Phase Participant Demographics and AT Usage

| Pseudonym | Age | State | Braille Notetaker | Refreshable Braille Display | Computer Screen Reader | Mobile Screen Reader | Screen Magnification |
|---|---|---|---|---|---|---|---|
| Participant 70 | 15 | CA | Yes | Yes | Yes | Yes | No |
| Participant 04 | 18 | PA | No | No | Yes | No | Yes |
| Participant 12 | 20 | IN | No | No | Yes | No | No |
| Participant 09 | 20 | NJ | No | Yes | Yes | No | No |
| Participant 35 | 20 | CT | No | No | Yes | No | No |
| Participant 11 | 21 | LA | No | Yes | Yes | No | No |

### 3.3 Data Collection and Analysis

I collected and analyzed the qualitative and quantitative data separately. Then I integrated the findings to answer research questions 1 and 3, mixing methods for the purpose of triangulation [Greene, 2007]. None of the quantitative data pertained to research question 2, so those findings emerged exclusively from the qualitative data analysis. Below I describe the data collection for each phase of the study.

*3.3.1 Qualitative Data Collection and Analysis.* In 2020, I conducted 16 remote semi-structured interviews via Zoom and collected five artifacts.

The interviews ranged in length from 24 to 109 minutes ($M = 66.6$). I used 10 probes to guide the semi-structured interviews:

(1) Can you tell me about the technologies that are used in your school and classes?
(2) Can you tell me about the AT that you use (e.g., **Job Access with Speech (JAWS)**, **Non-Visual Desktop Access (NVDA)**, **VoiceOver (VO)**, TalkBack, BrailleNote, BrailleSense, Braille display, Zoom, ZoomText, Fusion)?
(3) Can you tell me about other technology that you use in school (e.g., laptop, internet browser, email client, social media)?
(4) Can you tell me about a time when technology was used in one of your classes, and it was inaccessible to you? In other words, something about the technology or activity made it hard or impossible for you to participate.
(5) Can you tell me about a time when technology was used in one of your classes and it was accessible to you? In other words, something about the technology or activity made it easy or possible for you to participate.
(6) How do you know if a technology is accessible or inaccessible?
(7) Can you tell me about the times and places that you have experienced the most inaccessible technologies in school?
(8) What suggestions do you have for making classes where technology is used more accessible?
(9) What advice do you have for other BLV students about learning and working in classes where technology is used?
(10) Is there something else that you think I should know to better understand your experience with inaccessible technology in school?

I also invited participants to share relevant artifacts. Four participants shared a total of 5 artifacts. The artifacts ranged in length from 250 to 1,430 words ($M = 814.2$) and included two news articles, one blog post, one email, and one slideshow. I deidentified the interview transcripts and artifacts prior to conducting data analysis.

I analyzed the data using several rounds of emergent coding and employed several emergent coding techniques throughout (e.g., in vivo, value, and versus) [Saldana, 2016]. I also used analytic memos to construct an increasingly abstract understanding of the youth's experience. Throughout data analysis, I utilized the constant comparative method [Charmaz, 2014] to compare codes to data, codes to codes, memos to data, and memos to codes.

*3.3.2 Quantitative Data Collection and Analysis.* As discussed above, I obtained deidentified secondary data from the NFB for the quantitative phase. I was not involved in the design or administration of the survey. I received data the NFB collected between 2018 and 2020 through its instructional technology survey. In addition to a few demographic questions (see Table 4), the survey asked respondents about their experiences with inaccessibility in five categories of instructional technologies: school websites, homework platforms, eBooks, tests, and discussion boards. For

Table 5. NFB Survey Data Pertaining to Inaccessible and Accessible Instructional Technologies

| Pseudonym | Inaccessible School Website | Inaccessible Homework Platform | Inaccessible eBook | Inaccessible Test | Inaccessible Discussion Boards | Accessible Instructional Technology |
|---|---|---|---|---|---|---|
| Participant 70 | Yes | Yes | No | No | No | Yes, Google Classroom |
| Participant 04 | Yes | Yes, Skyward | No | No | No | Yes, School-created homework platform for finance class |
| Participant 12 | No | Yes, ALEKS Chemistry | No | Yes, Smarter Proctoring | No | No |
| Participant 09 | No | Yes, MyMathLab | No | No | No | No |
| Participant 35 | No | No | No | No | No | No |
| Participant 11 | No | No | No | No | Yes | Yes, Blackboard |

each category the survey asked if the respondents had encountered inaccessible technology in that category (yes or no), the name of the inaccessible technology (open ended), and how it was inaccessible (open ended). Additionally, the survey asked if respondents had encountered fully accessible technologies, the name of any such technologies, and how those technologies were used in school. See Table 5 for additional details. Some participants did not answer the open ended questions and the answers they provided were short. I analyzed the small amount of qualitative data from the survey along with the data from the qualitative phase. Due to the sample size and the descriptive nature of the data, I simply analyzed the quantitative data by counting.

### 3.4 Researcher Role and Reflexivity

I am congenitally blind and attended public schools in the United States for my entire primary, secondary, and tertiary education. Throughout my schooling, I was frequently excluded from learning due to analog or digital inaccessibility. I am also a former K-12 teacher of blind and disabled students and a teacher educator. Consequently, I have deep knowledge of the US K-12 system from three distinct vantage points. As a result of my lived and professional experiences, I believe the US K-12 system is inherently inequitable to BLV and other disabled youth. I also know firsthand that it is possible to facilitate technology-mediated learning that is equitable and accessible to BLV and disabled youth.

My positionality shapes the way I write. I use the language blind people use and prefer. For example, I use identity-first language (i.e., BLV person) rather than person-first language (i.e., person who is BLV) [Riccobono, 2020a] and I capitalize Braille. The language I use is often quite different from the language used in schools. For example, I use the term *teachers of blind students* to refer to the educators who are licensed to teach BLV youth. Most of the participants referred to their TBSs as a “teacher of the visually impaired (TVI)” or a “vision teacher.” Similarly, the youth used the term “visual” to refer to non-linear information (e.g., pictures, tables, diagrams). Customarily, I refer to this type of information as *spatial* to disrupt the dominant narrative that vision is the only means for interpreting non-linear information. In the findings, I retained the participants’ terminology offset by quotation marks.

In this study, I was both an insider and an outsider—but never a neutral objective observer. I did not know firsthand what it was like to be a student in 2020 and, therefore, was an outsider. However, as a blind person, I was an insider. I knew seven of the participants through the blind community, and I told the others I was blind to build rapport and trust, which is critical in transformative research [Mertens, 2012]. Consequently, the participants often related to me as a blind elder not an unfamiliar researcher. Alyssa pointed out the different vibe: "having a conversation about AT with another blind person and having the conversation with a sighted person, it's so different."

Consistent with the philosophical assumptions of the transformative paradigm, in collecting and analyzing the data from this study, I constructed an abstract understanding of the multiple realities of BLV youth's experiences using AT and instructional technologies in school. I did not discover a universal truth of a singular reality.

### 3.5 Trustworthiness and Limitations

To increase the trustworthiness of this research, I employed three strategies: reflexivity, triangulation, and a chronological memo bank [Lincoln and Guba, 1985]. In addition to triangulating findings within the qualitative data, I also triangulated findings between the qualitative and quantitative data.

The sample is the greatest limitation of this study. A sample of 22 is in line with the existing research with BLV youth participants discussed in Section 2.4, which had samples of 4–49 ($M = 13.4$; Mdn. = 8) and exceeds the sample size guidance of 5–10 that Lazar et al. [2017] offer in their HCI research methods text. That said, a sample of 22 is not a large portion of BLV youth age 13–22 in the United States. Had I conducted the study outside of the COVID-19 pandemic, it may have been possible to recruit more youth participants. Additionally, I employed purposeful and convenience sampling, not representative sampling. So, the sample in this study is not representative of the population. The sample is skewed toward youth who have been blind since birth, are age 18 and up, are learning through primarily nonvisual means (e.g., tactile, auditory), and are engaged in the blind community. Consequently, the findings may not fully represent the experiences of BLV youth who are younger, acquired blindness as teens, learn primarily using visual means, and are not engaged in the blind community. I encourage other scholars to explore the extent to which these findings generalize to a larger and more representative sample.

## 4 Findings

In this section, I address the answer to each of the three research questions in turn, beginning with research question one.

### 4.1 AT Usage

The participants used a variety of AT, including specialized hardware (e.g., RBDs), third party software (e.g., JAWS), and AT built into the operating system of a mainstream device (e.g., VO on iPhone). Ninety percent of the youth ($n = 20$) used a combination of AT, some using as many as five. For example, Kennedy, who was majoring in computer science, used NVDA on her Windows machine; VO on her iPhone, iPad, and MacBook; and an RBD.

All 22 of the youth used at least one screen reader. All 16 of the participants in the qualitative phase used VO as their mobile screen reader. Most of the youth ($n = 20$) used a computer screen reader. The youth I interviewed indicated their primary computer screen reader was JAWS ($n = 8$), ChromeVox ($n = 3$), VO on Mac ($n = 2$), and NVDA ($n = 1$). It is worth noting that the three participants who used ChromeVox on a Chromebook did so sparingly and did not find it useful. Alexis indicated the Chromebook was the most inaccessible technology she has used in school and Spartan referred to the device as "super trash."

Seventeen participants had access to refreshable Braille. Eleven participants used a Braille notetaker, a Braille-first tablet. Twelve participants used an RBD, a device that facilitates digital Braille output and input but has limited stand-alone capacity.

Four of the youth used screen magnification for some tasks (i.e., Zoom on Mac or ZoomText).

Table 6. Individuals Who Supported the Youth's AT Literacy Development

| Type of Individual | Primary Support | Secondary Support | Tertiary Support |
|---|---|---|---|
| Self | 5 | 1 | 2 |
| Blind AT Tutor | 1 | 1 | 0 |
| Unpaid Blind Mentor | 0 | 6 | 1 |
| School AT Specialist | 4 | 0 | 0 |
| TBS | 3 | 4 | 2 |
| Paraprofessional | 2 | 0 | 0 |
| Adult Rehabilitation Training | 1 | 0 | 0 |

Table 2 provides additional detail about AT usage among the 16 participants in the qualitative phase and Table 4 provides additional data about AT usage among the 6 survey participants.

### 4.2 Developing AT Literacy

The participant's community and school contexts were quite varied but several patterns were evident in both how and when they developed AT literacy. They generally did not begin developing AT literacy until upper elementary school and frequently were forced to direct their own learning because they were not getting the support they needed at school. As the youth directed their own learning, they solicited insight from other BLV AT users they knew.

The majority of the youth ($n$ = 13) began developing their AT literacy in third grade or later, and four of those 13 did not begin the work until middle or high school (see Table 2). Juliana and Callie's experiences, for example, were similar, though their schooling contexts were quite different. "I've known how to use a BrailleNote since fifth grade, but like iPads and stuff, I began learning how to use when I was about 13 or 14 [eighth grade]," Juliana explained. Callie echoed, "[w]ell, I kind of started a little bit in fourth grade with the BrailleSense. I did a lot of typing training and stuff, but I didn't start using the laptop in class till eighth grade." Like Callie and Juliana, many of the youth got to learn some AT in upper elementary school, but middle school is when learning AT became more of a focus.

Jacob, Fifer, and Lily had the unusual opportunity to start learning AT as very young children. After sharing that he began learning AT in kindergarten, Jacob pointed out that he was lucky to have had such early access to AT instruction: "I am very grateful. It's definitely a blessing. A lot of kids are less fortunate."

The youth collectively received or solicited support from a range of people to develop their AT literacy, including themselves, school personnel, and other BLV AT users. As Table 6 shows, most of the participants ($n$ = 14) used multiple supports to develop their AT literacy. For example, Alexis and Fifer were primarily self-taught with secondary support from unpaid blind mentors and tertiary support from their TBSs. Hannah and Jacob were outliers in the group; they developed their AT literacy with the exclusive support of their TBSs.

Most of the youth engaged the expertise of BLV AT users, themselves included, to develop their AT literacy. Five of the participants were primarily self-taught, and three were partially self-taught. To teach themselves, the participants read user manuals, found online resources, and "played around" with the technology. Nine of the youth had the support of BLV elders and/or peers. Those people were frequently unpaid mentors that the youth met through events in the blind community. In a few instances, the blind elders were employed by the school or hired as tutors. In one instance, the BLV mentors were the participant's family members.

To direct their own AT literacy development, either by supporting themselves or leveraging the expertise of BLV mentors outside of school, the youth had to have the metacognitive awareness to know (1) what they did not know and (2) what kind of support they needed to develop the missing knowledge. The youth who directed their own AT literacy development often did so because their school failed to provide the support they needed. Alyssa and Kennedy shared:

> So, I learned a good bit on my own because [the school] was not going to pay for someone to teach me.... I'm also able to ask [blind mentor] some AT questions, stuff where I feel like I should have already learned this or know this, but I don't. (Alyssa)

> I really didn't have a good TVI at all. And as a result, I literally had to teach myself... it's really in middle school when I actually had to literally put the pedal to the metal and actually teach myself how to use the technology. Because I didn't have adequate training and I wasn't going to let the school system that was inadequately preparing me for life stop me from being successful... I also had a lot of [blind] friends that I met through various events, that I literally FaceTime-d them at night and I'd be like, "Okay, how do you do this? Because like I said, I'm trying to teach myself"... I also had some help from a [blind] private contractor that my parents had to hire. So, I'd literally go to the city like twice a week to work with this private contractor on JAWS. (Kennedy)

The youth indicated that the school personnel often did not have the knowledge to teach them how to use AT. Rebecca and Fifer explained:

> ... my vision teacher didn't know too much about how to use VoiceOver... So basically, my vision teacher showed me a little bit of it, but then again, it was a lot of me just experimenting with it and trying to figure it out on my own. And then watching some videos online or talking to other blind people who use it... my vision teacher now, sometimes she'll ask me, "how do you do this with VoiceOver and stuff? (Rebecca)

> I think this is a problem that a lot of people face because when a teacher doesn't know how to use something they can't really coach you in how to do it. This was something I encountered with a lot of the [Braille] notetakers... [they] were not things that the teacher could show me how to use. (Fifer)

In contrast, some of the youth received primary support from school personnel in developing their AT literacy. Nine of the participants' primary support for developing AT literacy came from a school employee, including AT specialists, TBSs, and paraprofessionals. Unsurprisingly, the three participants who attended schools for the blind received primary support from school personnel. Hannah received primary support from public school personnel; "I started using the Brailliant [RBD] around sophomore year.... I learned a lot from my TVI at the time... She just said, "this is how you do this." And I caught on quickly" (Hannah).

Most of the youth's AT literacy development began by learning either QWERTY touch typing or how to use a Braille notetaker. VO on a mobile device was often the first screen reader the youth learned to use. In most cases, the youth did not get to focus on learning computer-based screen readers (e.g., JAWS) until they were teenagers. Rose, for example, learned JAWS after high school; "[p]eople really didn't teach me that much [JAWS] while I was in school.... I learned JAWS mainly from going to the Louisiana Center for the Blind for their adult independent living program" (Rose). Kennedy was employed by her university as an AT and accessibility specialist, and one of her key responsibilities was to support other BLV university students in developing their AT literacy.

> But obviously some of these blind students were very new JAWS users and it's not their fault. It's not their fault that they didn't know JAWS that well.... So basically, I'd set up some training sessions... I had to start from almost the basics or very not that far into it. So maybe I'd have to teach them how to use F6... Or maybe I'd have to teach them how to use JAWS OCR or NVDA object navigation... (Kennedy)

The type of AT the youth used, their lower AT literacy levels, and their schooling contexts, which often forced them to figure things out on their own, influenced how they differentiated between accessible and inaccessible instructional technologies.

### 4.3 Differentiating between Accessible and Inaccessible Instructional Technologies

The youth reported that their schools used a wide variety of instructional technologies, including learning management systems (e.g., Google Classroom), office applications (e.g., PowerPoint), student response systems (e.g., Kahoot), subject-specific technologies (e.g., Khan Academy, MyMathLab, Vocabulary.com), etextbooks, and digital standardized tests.

All 16 of the youth I interviewed felt most of the instructional technologies used in their schools were either partially or fully inaccessible to them. Moreover, half of the survey participants indicated their school did not use any fully accessible technologies. The youth felt **science, technology, engineering and math (STEM)**-specific instructional technologies (e.g., science simulations, Khan Academy, math games) were the most inaccessible, both in frequency and severity. Captain Marvel explained, "in science class, I probably experience the most inaccessible things." Participant 12 explained that "[n]one of the exercises in the [chemistry] program are able to be navigated or read with screen access software." The inaccessible STEM instructional technologies prohibited the youth from doing math in digital Braille, collecting data in the lab, completing exercises, reading graphs, and engaging with simulated labs. Across STEM classes, most of the digital math and science notation blind youth encountered rendered junk Braille that was difficult to parse. Jada shared, "it was difficult to read the question, especially if it was a fraction because it wasn't all on one line like a typical fraction... There was no fraction indicator" so "I would interpret that as 13 and not one third." In the Nemeth Braille code, the simple fraction one-third should appear on one line and have five characters: OpenFractionIndicator, 1, /, 3, and CloseFractionIndicator.

As a result of inaccessible instructional technologies, the youth were often excluded from technology-mediated learning. In Spartan's words, "it's kind of hard to get stuff done when it [technology] doesn't work." Jacob elaborated:

> You've [teacher] set the whole class with handouts and stuff to use this website for the next three weeks to compose a project and now I am stranded on this desert island because that site doesn't work. You can't just re-change your whole teaching plan, especially when you've distributed it. (Jacob)

Through data analysis, I determined that the youth evaluated accessibility on two dimensions: (1) learning to use the interface and (2) using the interface to learn. From the youth's perspective, accessible instructional technologies were both easy to learn to use and easy to use to learn. Across the two dimensions, the youth described nine factors that contributed to the accessibility of a technology (see Table 7).

I employed questions as names for the factors to convey the inquiry process the youth used to determine if an instructional technology was accessible. Rose explained the inquiry process, "I have to go and explore myself." Ashley expanded on Rose's point:

> You got to just play with it a little bit. You got to see what works and what doesn't, what you need from the technology. You just gotta mess around with it a bit, see what works, see what doesn't. (Ashley)

The youth used an inquiry process because "when you download an app, there's nothing that says, 'Hey, this is going to work"' (Captain Marvel). During their accessibility inquiry process, the youth tacitly asked the nine questions in Table 7 to determine if the instructional technology was (1) easy to learn to use and (2) easy to use to learn.

Table 7. Youth Evaluation of Instructional Technology Accessibility

| Factor | Dimension 1: Learning to Use | Dimension 2: Using to Learn |
|---|---|---|
| 1. How complex is the interface? | ✓ | |
| 2. Does navigating the interface require knowledge I have not yet had a chance to develop? | ✓ | |
| 3. Does the interface help me communicate with my sighted peers and teachers about using this tool? | ✓ | |
| 4. Are the buttons labeled and do the labels make sense? | ✓ | |
| 5. Can I access the interface on multiple devices running different operating systems and browsers? | ✓ | ✓ |
| 6. How "visual" is the presentation of the information I'm supposed to learn? | | ✓ |
| 7. What type of access do I have to information that is being presented "visually?" | | ✓ |
| 8. Can I learn seamlessly in digital Braille? | | ✓ |
| 9. Can I do everything my peers can do? | | ✓ |

*4.3.1 Learning to Use Instructional Technology.* As discussed in Section 4.2, the participants often had to direct their own technology learning—a reality that extended to learning how to use instructional technologies with AT (e.g., using Google Docs with JAWS). Unlike their sighted peers, the 13 participants who did not attend a school for the blind were learning in environments devoid of natural supports for AT-mediated learning. Namely, their teachers and peers were not AT users; so, they could not rely on them for just-in-time support. Moreover, the individuals who could support the youth in learning to use new interfaces with their AT were not in the classroom and frequently not even in the building. Consequently, an interface's learning curve contributed significantly to the youth's accessibility evaluation. Within Dimension 1, Learning to Use, the youth discussed five factors.

*Factor 1: How complex is the interface?* From the youth's perspective complex interfaces were inaccessible. Conversely, accessible interfaces were simple, uncluttered, and had streamlined workflows. Simple interfaces used linear as opposed to "visual" layouts.

> I would say that a technology that is accessible is easily navigable with a screen reader. I think that technologies that are accessible generally don't rely too much on visual layouts or anything like that.... Technologies that are inaccessible tend to rely on visual layouts or pictures or other things that make them difficult to navigate with the screen reader. (Fifer)

Uncluttered interfaces had a limited number of actionable elements (e.g., items to tab through). Jacob explained, "[t]here has not been a page... that has more than three or four items that you scroll through with the thumb keys. It's very uncluttered." The youth characterized streamlined workflows as those with easy to execute steps and no extraneous steps. Lilly compared the experience of uploading an assignment in the Google Classroom web app vs the mobile app to explain what a streamlined workflow was like:

> With the website... you would go to get the file or copy the file over to Classroom. And it was just a whole process. Like it would take you to drive and then it would take you to like docs... I don't know, it was just weird and I didn't like it. I liked the app way better... I could just do like three things and then the file would be uploaded, it wasn't this whole process... (Lilly)

When interfaces were simple, uncluttered, and streamlined it was easy for the youth to find what they were looking for and quicker to accomplish tasks. Jada summarized, "accessible technology is really simple to navigate, really easy. It doesn't take that long to figure out... You can find what you're looking for."

In describing complex interfaces, the youth frequently compared the simplicity of a mobile app to the complexity of a web app. Like Lilly, Juliana felt the Google Classroom mobile app was a much simpler interface than the web app:

> The app on my iPad, I can just easily scroll through things, and I know where everything is, but on the desktop, I have to constantly push tab or the arrow keys and navigate around all of these boxes that say blank and stuff. (Juliana)

*Factor 2: Does navigating the interface require knowledge I have not yet had a chance to develop?* The youth felt that interfaces that they could navigate with the knowledge they already possessed were accessible, and interfaces that required digital navigation techniques they had not yet learned were inaccessible. Many of the instructional technologies the youth encountered did not meet their access needs with respect to this factor. Callie explained the frustration she encountered learning how to use Google Docs, which required digital navigation knowledge she had not yet developed:

> Just how to get to the comments was really irritating because it's like there's commands, there's so many new commands. And then having your cursor knowing exactly where it is, I kind of had to learn about that because it's a little bit different than in JAWS. It says your cursor is on something, but it could be one space to the right and that was different than in JAWS. (Callie)

Kennedy, an expert AT user, took this factor one step further and argued that an accessible technology is "easy to navigate, no matter the ability of the screen reader user." Kennedy explained while she could navigate a number of instructional technologies, such as WebEx, she did not consider them accessible because her BLV peers, who were novices, would not be able to navigate them without developing additional knowledge.

The instructional technologies that did not meet the youth's digital access needs on this factor required at least one of four types of knowledge. One, knowledge of how to use an intermediate or advanced screen reader feature (e.g., NVDA object navigation, JAWS OCR). Two, knowledge of intermediate or advanced interaction techniques, such as using F6 to move between panes in a Windows application. Three, knowledge of novel application-specific keyboard commands, such as those required to use Google Docs and Drive. Four, knowledge of the inaccessible practices developers employ and where they employ them and the deductive reasoning skills to use that knowledge to make meaning of inaccessible elements or modes of interaction.

When the youth encountered interfaces that required digital navigation knowledge they did not possess, some of the youth were able to spend time developing that knowledge. They did so by trial and error or by consulting with a more experienced BLV AT user. Those who attended schools for the blind were sometimes able to collaborate with their classmates to develop the requisite knowledge to crack tricky interfaces. The youth provided several examples of interfaces that they once called completely inaccessible but at the time of the interviews considered somewhat accessible because their digital navigation knowledge was more advanced. Ashley relayed her experience with Google Classroom at the school for the blind:

> I don't really remember much of the early stages of Google Classroom, just that we all were like, "This app sucks. Please do not ever have us use it again."... I just know that I didn't like it, it was very bad with VoiceOver, it was not accessible. We went back to it maybe a year later in a different class. That's when the learning process started where we [students] just started learning and teaching each other how to use it, what worked, what didn't work and all that stuff. (Ashley)

*Factor 3: Does the interface help me communicate with my sighted peers and teachers about using this tool?* As discussed above, most of the participants attended schools where the other students and the teachers were sighted. Consequently, they needed interfaces to facilitate, rather than encumber, communication between them and sighted people, particularly with respect to navigation. The youth encountered a number of interfaces where the difference between the visual and nonvisual presentation made it hard for them to talk with sighted people about using the technology. Sometimes it was a discrepancy in the order elements were presented that encumbered communication:

> I remember one time when I was talking to someone [sighted] about the page layout I said, "Oh, this heading on top here is really nice because it leads to this menu that's easy to navigate." It actually wasn't on top it was just the way JAWS was reading stuff... it creates a disconnect between the way I have to talk about a page and the way they [sighted peers] are talking about a page. (Fifer)

Other times the visual semantics encumbered communication, particularly when the visual semantics did not accurately convey the type of element. If a link was visually styled to look like a button, sighted teachers would give instructions such as "find X button." Hearing this instruction, the participants logically attempted to use their screen readers button navigation functions to find X button to no avail.

> She [sighted teaching assistant] said, "Click on the lessons tab." But here I was looking for the lessons tab, and it turns out I was supposed to have been looking for the lessons link... There's a difference between a tab and a link. Part of the issue was the terminology, tab versus link, button versus whatever else... So that really messed me up because here I am, wondering, where in the world can the lesson tab be, when I was supposed to have been looking for the lesson link... the terminology that was used really confused me, especially when someone was trying to explain it, which was most often the case because I really couldn't figure out the site at all. (Jada)

Alyssa explained that when there are substantial differences between the visual and nonvisual presentation of an interface BLV and sighted people "speak a different language" about using the technology and that inhibits mutual aid and learning.

> ... when you have both blind and sighted users using your product together, you're going to run into issues because it's going to be like we're speaking different languages... So, it's going to be hard for us to communicate how we're using the same piece of software. (Alyssa)

*Factor 4: Are the buttons labeled and do the labels make sense?* Unlabeled or poorly labeled buttons were a common source of frustration for the youth, and in Jacob's words made interfaces "wicked inaccessible." Jacob explained that sometimes he would discover what a button did by pushing it and observing the effect. He used this approach on websites that he frequented and subsequently memorized each unlabeled button's function. Though the approach Jacob described was an intermediate AT user hack, which a handful of the participants' used, they did not feel they should have to memorize button functions. Moreover, sometimes an unlabeled button's effect was not nonvisually observable. Captain Marvel encountered that problem repeatedly with the simulations her science teachers used: "I just have a screen that says the word 'button' a bunch of times and it's not very helpful."

Other times the buttons were labeled, but the labels were vague or confusing. Kennedy offered WebEx as an example of an interface with poorly labeled buttons:

> For one, you have button labels that are obscure—that don't mean anything. For example, [in WebEx] when you're going to start a meeting or join a meeting, basically what it will say is, "Kennedy's personal video." And then it will say the meeting name. So, like, "Kennedy's Personal Video, Interview. Start Video, Join Meeting button." That'd be all one button label. (Kennedy)

Using her expert AT skills, Kennedy figured out what all the vaguely labeled WebEx buttons did and then, as part of her job at the university, taught all of the other BLV students how to navigate the inaccessible interface so they could participate in COVID emergency remote learning.

*Factor 5: Can I access the interface on multiple devices running different operating systems and browsers?* As outlined in Tables 2 and 4, the youth used a range of technologies as their primary device. Furthermore, many of them carried two or more devices with them to class. The youth felt that technologies that were compatible with multiple operating systems were the most accessible. When asked what a completely accessible instructional technology would be like, Rose said, "I could use it on either an iPad, an iPhone, or a computer." Multiple platform compatibility made it easier for the youth to learn to use the technology for two key reasons. First, it was more likely that they would be able to access the instructional technology from their primary device, on which they had more robust digital navigation knowledge. Second, an instructional technology that worked on multiple platforms was more likely to be at least somewhat usable on one of the youth's devices. Jacob shared that he kept a running hard copy Braille list of which device each instructional technology was most usable on; at the time of the interview, the list was four and a half pages long. He explained how he used the list in class:

> Oh, I have to go to vocab.com, that works better on the iPad. Pulls out the iPad.... Some others like... work better on the BrailleNote Touch... I'll go to it [new instructional technology] on both [devices] and then add it to the list as which one it works better on. Some of them have both next to them. Some of them work fine on both, but I default directly to my BrailleNote... I'll go to the iPad if I have to... (Jacob)

Additionally, instructional technologies that were compatible with multiple platforms were easier for some of the youth to learn with. In that way, Factor 5 straddles Dimensions 1 and 2. Some of the youth preferred to start their work on one device and finish it on a second device to take advantage of each devices' affordances. Rebecca was one of the participants who employed this strategy: "I would type my word documents on my iPad, but it was pretty difficult for me to edit my word documents on my iPad. So, I would prefer to edit my documents on my home computer" (Rebecca).

#### 4.3.2 Using Instructional Technology to Learn.

In addition to being easy to learn to use, according to the youth, accessible instructional technologies are also easy to use to learn. After all, instructional technologies are designed to facilitate learning. The four factors that comprise Dimension 2 delineate what the youth felt made an instructional technology easy to use to learn.

*Factor 6: How "visual" is the presentation of the information I'm supposed to learn?* The youth frequently used the word "visual" to describe inaccessible technologies. From the youth's perspective, there was an inverse relationship between accessibility and a technology's "visual" quotient. That is, highly "visual" digital information was extremely inaccessible. Generally, the youth used the term "visual" to classify any meaning conveyed through something other than machine readable linear text (e.g., pictures, tables, slideshows, and simulations). "[A] rule of thumb for me is probably if it's text, I'm like, 'Oh, that'll be pretty accessible"' (Rebecca). The "visual" classification extended to items sighted people might not consider "visual," such as pictures of text, stylized text that uses visual aesthetics to convey some meaning (e.g., red font means X), and videos without descriptive audio. In personifying inaccessible technology, Callie highlighted the "visual" quotient. If inaccessible technology was a person, "they would be interested in everything being visual, no sound at all, just completely visual, visual, visual. And they would never describe anything if you watched a movie with them" (Callie).

*Factor 7: What type of access do I have to information that is being presented "visually?"* In addition to the "visual" quotient, the type of access participants had to information presented "visually" was a factor they considered in evaluating the accessibility of instructional technology. Far too often, the youth had no access whatsoever to the "visual" information; images had no alt text, videos frequently had no meaningful audio, and tabular data was presented as images sans alt text. Participant 09 explained that in MyMathLab "some but not all graphs have verbal descriptions [i.e., alt text]." Similarly, in Captain Marvel's classes "a lot of things have pictures, but none of those have alt text."

When the youth had some access to the "visual" information they rarely got the information in the nonvisual format they found most useful for learning. Many of the youth indicated it was easiest and most equitable to learn with tactile graphics, video description, properly tagged tables, and hands-on demonstrations. For example, long written or spoken descriptions of educational images were too cognitively demanding to be useful learning tools. Similarly, video demonstrations of novel concepts or skills without video description were insufficient for learning, and in STEM subjects even videos with descriptive audio were often insufficient.

To learn effectively, the youth needed the "visual" information in a spatial nonvisual format (e.g., tactile graphic, 3D model, real object). For example, a text description of a calculus figure was taxing for Sam to decipher, but an analog tactile graphic of the same figure was easy to understand and use as a learning tool.

> [Test] just gives a description of the graph. That's hard for anyone to visualize, you know, having this big, long description of a graph and then you have to use that to answer the question. It's not right because feeling the graph is seeing the graph for blind people, and if my sighted peers can have the graph in front of them when taking the test, then I should be able to have that too. (Sam)

Likewise, a video of a science experiment was incomprehensible to Jada, but a live demonstration where she could explore the lab setup and tactually observe each step would have been understandable. "There's too many visuals in the video. It's hard to envision... I've never seen a bucket of antifreeze before, or I've never had to mix two gallons of antifreeze with two gallons of Mix-It-All or whatever" (Jada). And while an image of a table was useless, several of the youth reported that an appropriately tagged table was a surprisingly useful learning tool.

*Factor 8: Can I learn seamlessly in digital Braille?* As outlined in Table 3, Braille was an important learning tool for many of the youth. Consequently, Braille support was a factor upon which youth judged the accessibility of an interface. According to the youth, the most accessible technologies allowed them to navigate using the keys on their Braille notetaker or RBD, use Braille entry to compose textual and numeric content, and read textual and numeric content in accurate digital Braille. "I want the option to use either speech or Braille output and input, having both options makes it more accessible to me" (Rose). Several of the youth found it quicker to use Braille input for navigation and data entry. "[With speech] it'll take you forever because you have to listen to everything. But with a Braille display, you can read what's on the screen... and it goes much faster" (Jada). Additionally, the youth wanted the flexibility to switch to tactile reading to avoid the limitations of auditory reading, particularly in English and math classes. "I use my refreshable Braille display a lot when I'm writing essays, because when you're editing, JAWS isn't going to catch everything, so you also need to read it with your fingers" (Callie). The frequency with which the participants used Braille instead of or in addition to speech varied, some used Braille almost exclusively, and others used Braille only for discrete tasks where they felt speech was cumbersome.

*Factor 9: Can I do everything my peers can do?* Another key factor in the youth's accessibility evaluation was how much functionality they had access to in comparison to their sighted peers. Fully accessible interfaces provided BLV and sighted youth the same functionality. Very few of the instructional technologies the youth encountered met this bar. The youth considered an instructional technology mostly accessible if they could access enough functionality to successfully complete the assigned activity. The participants labeled an interface partially accessible if it gave them access to some of the functionality they needed to complete the assigned activity, and they could use their AT skills to quickly and independently work around the functionality to which they did not have access. For example, Jacob could not access comments people left him in the Google Docs app, but he was able to use the autogenerated emails and his deductive reasoning skills to work around the inaccessible comment interface.

The youth considered an instructional technology mostly inaccessible if (1) it had a separate skeletal interface for BLV users or (2) it forced them to employ a sighted human as a conduit to access some portion of the interface required to complete the assigned activity. For example, "[w]e play Kahoot and the teacher has to read the questions and the option choices because VoiceOver won't do that" (Juliana). Likewise, Participant 12 explained that "all homework in the [ALEKS Chemistry] program must be read" to them by a sighted person. The youth considered an interface fully inaccessible if they did not have access to any of the functionality. Captain Marvel encountered many fully inaccessible STEM instructional technologies:

> "I'm not able to do the same work as everyone else because usually best case scenario, my aide watches what's happening, and I kind of get secondhand information. I don't get to watch like the fun virtual things or play the games, which is the point of doing it." (Captain Marvel)

## 5 Preliminary Design Guidelines for Accessible Instructional Technologies

Based on the wisdom the BLV youth in this study shared about the AT they use, how they developed AT literacy, and how they differentiate between accessible and inaccessible instructional technologies, I offer six preliminary design guidelines for accessible instructional technologies targeting secondary-school-aged youth. I position these design guidelines as preliminary because they are an early waypoint, not an end point, on the long journey toward accessibility guidelines that address BLV youth's needs. Table 8 explains how the six design guidelines below align with the nine factors from Section 4.3.

(1) *Conform with the current version of WCAG*. The current version of WCAG should be the accessibility floor for instructional technologies. If the instructional technologies the youth in this study encountered were compliant with WCAG, they would not have found unlabeled buttons, images without alt text, or inaccessible tables. Moreover, WCAG compliant instructional technologies would support Braille input and output, which the youth indicated is crucial for their learning, particularly in English/language arts and STEM classes. Developers of non-web instructional technologies can follow the WCAG2ICT guidance document [Lawton Henry, 2023] to ensure compliance.

(2) *Provide scaffolding for novice AT users*. The participants shared that they need instructional technologies to be easy for them to learn to use by themselves or in a room full of people who access technology in a completely different way. Some of the instructional technologies the participants found inaccessible were likely in their Zone of Proximal Development [Vygotsky et al., 1978], but without a more experienced other to scaffold their learning they felt lost and frustrated. Given BLV youth's educational contexts, the requisite scaffolding needs to

Table 8. Alignment between 9 Factors and 6 Design Guidelines

| Factor | 1. WCAG Conformance | 2. Scaffolding for Novices | 3. Simple Interfaces | 4. Facilitate Communication | 5. Accessible Spatial Information | 6. Multiple Operating Systems |
|---|---|---|---|---|---|---|
| 1. How complex is the interface? | | | ✓ | | | |
| 2. Does navigating the interface require knowledge I have not yet had a chance to develop? | | ✓ | | | | |
| 3. Does the interface help me communicate with my sighted peers and teachers about using this tool? | | | | ✓ | | |
| 4. Are the buttons labeled and do the labels make sense? | ✓ | ✓ | | | | |
| 5. Can I access the interface on multiple devices running different operating systems and browsers? | | | | | | ✓ |
| 6. How "visual" is the presentation of the information I'm supposed to learn? | | | | | ✓ | |
| 7. What type of access do I have to information that is being presented "visually?" | ✓ | | | | ✓ | |
| 8. Can I learn seamlessly in digital Braille? | ✓ | | | | | ✓ |
| 9. Can I do everything my peers can do? | ✓ | ✓ | | | ✓ | |

be digital, as more experienced humans are unlikely to be present in the classroom given the "dismal" (Zhou, 2011, p. 205) state of teachers' AT knowledge. Therefore, instructional technologies need to provide sufficient scaffolding for novice youth AT users. The present study does not furnish sufficient knowledge to determine precisely what scaffolding BLV youth want and need. Substantial additional research is required, a topic I take up in Section 7.

(3) *Create simple interfaces*. Simple interfaces, to the participants, were those that were uncluttered and employed streamlined workflows. The youth often pointed to mobile apps as examples of simple interfaces and desktop/web apps as complex. The instructional technologies that were the easiest for the youth to learn to use were those that (1) had a limited number of actionable elements to tab through on each screen and (2) had workflows with only a handful of steps.

(4) *Facilitate communication between BLV and sighted users*. BLV youth are most often using instructional technologies alongside sighted peers and/or teachers. Consequently, instructional technologies need to facilitate, rather than encumber, communication between BLV and sighted users. BLV youth need to be able to follow the navigation instructions a sighted teacher is likely to give to their class of mostly sighted students, and they need to be able to collaborate with their sighted peers and teachers to create work products. Interfaces that convey the same meaning through both visual and nonvisual semantics facilitate communication. For example, if a button element "looks" like a button, a sighted teacher is likely to instruct students to "click on X button." A BLV student who has learned how to quickly locate buttons with their screen reader would be able to follow the teacher's instruction.

(5) *Help teachers produce accessible spatial information*. Much of the inaccessible spatial information (e.g., images of equations, instructional videos without descriptive audio) that impeded participants' learning was created by their teachers. Instructional technologies need to help teachers, who often lack accessibility knowledge [Shaheen, 2022b], learn how to create accessible spatial information. Conformance with Part B of the **Authoring Tool Accessibility Guidelines (ATAG)** [Lawton Henry, 2022] would provide some of the supports teachers

will need to produce accessible spatial information. But the results of this study indicate, in a secondary school context, teachers are likely to need guidance beyond ATAG to create accessible spatial information, particularly in STEM subjects. The participants explained that alt text and video description were frequently insufficient for learning due to the cognitive demand. The youth often found it easier to learn spatial information with analog materials such as tactile graphics, tangibles, and live demonstrations. While instructional technologies are unlikely to support the authoring of these analog materials, instructional technologies could prompt teachers to consider developing analog materials to support BLV students. Furthermore, instructional technologies could help teachers write more useful alt text by directing them to guidelines for writing descriptions of educational images, such as those developed by The DIAGRAM Center (DIAGRAM Center and National Center for Accessible Media, 2014).

(6) *Develop for multiple operating systems.* Instructional technologies should be compatible with multiple operating systems to ensure BLV youth can use the interface on their primary device. The youth felt it was easiest to learn to use instructional technologies with their primary device, and the participants used a variety of primary devices. Participants' primary devices ran five operating systems: Android (i.e., BrailleNote Touch Plus and BrailleSense; $n = 5$), Windows ($n = 5$), iPadOS ($n = 4$), iOS ($n = 2$), MacOS ($n = 1$). Furthermore, instructional technologies that are compatible with multiple operating systems will be easier for some BLV youth to learn with. Some participants preferred to start their work on one device and finish it on another to leverage the affordances of each device.

## 6 Discussion

The findings from this study update the knowledgebase about BLV youth's AT usage and compliment and extend the knowledgebase about designing accessible instructional technologies.

### 6.1 Learning and Using AT Then and Now

A comparison between the results of the present study and D'Andrea (2012), the most recent study of secondary-school-aged AT users, reveals relative consistency in how BLV youth learn to use AT but significant shifts in the type of AT youth use.

According to the results of both studies, BLV youth often learn AT outside of school by teaching themselves or learning from other BLV people. Roughly half of the participants in both studies were partially or exclusively self-taught. Conversely, only 1 participant in the 2012 study and 2 participants in the present study learned AT exclusively from their TBS. One notable difference was the number of participants who learned from BLV peers or elders. One-third ($n = 4$) of the 2012 participants learned from other BLV people compared to 56.25% ($n = 9$) of this study's qualitative phase participants. I attribute this difference to the fact that I recruited some participants through the blind community. Many of the youth in this study had greater access to other BLV people than youth who are not engaged in the blind community. This points to an advantage of being engaged in the community—the opportunity to learn from other BLV people.

Like the youth in D'Andrea's 2012 study, the 22 participants in this study used a wide variety of AT and most used multiple devices/software. However, the results of this study highlight three shifts in AT usage over the last decade.

First, there has been a shift in the type of refreshable Braille devices BLV youth are using. In both studies refreshable Braille usage was high, 83.3% ($n = 10$) in 2012 and 77% ($n = 17$) in the present study, but Braille notetakers are no longer BLV youth's only method for accessing refreshable Braille. In D'Andrea's study almost all of the participants were using Braille notetakers

(83.3%; $n = 10$) compared to only 50% of participants ($n = 11$) in this study. Additionally, 12 of the participants in this study were using RBDs, a type of AT D'Andrea's participants were not using.

Second, there has been a notable increase in the use of computer screen readers and a shift in the type of computer screen readers BLV youth are using. The 66% ($n = 8$) of D'Andrea's participants who used a computer screen reader all used JAWS. In this study, 90% ($n = 20$) of the youth used a computer screen reader. Among the qualitative phase participants ($n = 16$) who provided additional details about their screen reader(s), JAWS was the most common screen reader ($n = 8$), but six youth used another computer screen reader (NVDA = 1; ChromeVox = 3; VO on Mac = 2).

Third, mobile device and screen reader use has expanded dramatically. D'Andrea mentioned several participants were using a mobile phone but did not specify how many. In the present study, all of the youth in the qualitative phase ($n = 16$) were using an Apple mobile device with VO. In fact, seven of the youth identified their Apple mobile device as their primary AT/IT. Three of those seven youth paired their mobile device with an RBD as their primary AT/IT stack.

### 6.2 Comparing Design Guidelines

In Section 5, I offer six preliminary design guidelines for accessible instructional technologies that are grounded in the wisdom BLV youth shared. Here, I compare the guidelines from Section 5 with nationally recognized guidelines, specifically WCAG and **Universal Design for Learning (UDL)**, as well as design guidelines that have emerged from HCI research with BLV youth. I explain that the guidelines I advance in Section 5 complement and extend existing guidelines.

The youth in this study articulated some digital access needs that are addressed in the adult-focused guidelines of WCAG, indicating some overlap with BLV adults' digital access needs. For example, the youth needed properly labeled buttons, good semantic structure, and tables with column and row headers. Consequently, in the first design guideline, I propose conformance with WCAG as the accessibility floor for instructional technologies. However, WCAG does not currently address all of the digital access needs that the youth shared, as I articulate in design guidelines two through six. These additional needs are likely connected to the developmental profiles of secondary-school-aged youth and the educational context in which instructional technologies are used. For example, the youth found images to be a barrier. But, in the context of a classroom, the youth needed more than good alt text, which is required by WCAG, to learn with the image. Moreover, the youth articulated a need for simple interfaces with few actionable items and workflows with few steps. This need may be connected to the youth's developing executive functions, top-down cognitive processes for controlling behavior (e.g., inhibitory control, problem-solving, and planning) that continue to develop through young adulthood [Best and Miller, 2011; Diamond, 2013].

Like WCAG, UDL has been incorporated into US law (e.g., Every Student Succeeds Act) and, as a result, is used extensively in K-12 education. UDL broadly addresses designing accessible teaching and learning [CAST, 2018] and does not tell designers or educators how to construct accessible technologies. However, UDL is germane to this discussion because the guidelines I propose in Section 5 are for instructional technologies—technologies that are used for teaching and learning.

There are three UDL checkpoints that are synergistic with the guidelines I propose in Section 5.1. UDL Checkpoints 1.3 (offer alternatives for visual information) and 4.2 (optimize access to tools and assistive technologies) [CAST, 2018] align with design guideline 1 from Section 5, which requires conformance with WCAG. Additionally, UDL Checkpoint 8.3 (foster collaboration and community) [CAST, 2018] aligns with design guideline 4 from Section 5, which says accessible instructional technologies facilitate communication between BLV and sighted users.

The design guidelines I advance in Section 5 are also complimentary to instructional technology design guidelines proposed by other scholars who have conducted research with BLV youth. Two prominent themes are evident across the four existing sets of guidelines [Brulé et al., 2016;

Metatla et al., 2020; Milne et al., 2014; Sánchez, 2008]: (1) promote collaboration between BLV and sighted learners and (2) design for nonvisual and visual modes of learning by incorporating multisensory information. These two themes are also evident in the preliminary design guidelines I offer in Section 5.

Collaboration is a key aspect of classroom life and an important method for learning in secondary education. Therefore, accessible instructional technologies should promote collaboration. In design guideline 4, I assert that instructional technologies should facilitate communication between BLV and sighted people so they can (1) learn to navigate a new interface together and (2) collaboratively create work products. Similarly, Milne et al. [2014] suggested that educational games should be designed for collaborative play between BLV and sighted people. Moreover, Brulé et al. (2016) suggested that technology designed for the classroom should facilitate collaboration.

Developing accessible instructional technologies requires (1) rejecting the hegemony of vision in education, (2) intentionally designing for both nonvisual and visual modes of learning, and (3), incorporating multisensory information. Previously, Brulé and Bailly called for designers to join the sensory turn, a movement in the humanities and social sciences [Bull et al., 2006], and explicitly question "which, and whose, sensory knowledge they support, and how it defines the experience they propose" [Brulé and Bailly, 2018, p. 1]. I echo that call. In design guideline 5, I posit that instructional technologies need to (1) prompt teachers to question the dominance of visual information in their lessons and (2) encourage teachers to incorporate tactile graphics and tangibles. Correspondingly, Metatla et al.'s [2020] first design guideline called for the use of multisensory information to "equalize access and meaning making:" (p. 143).

## 7 Future Research

The findings from this study along with the literature reviewed in Section 2.4 provide a foundation for the substantial additional research that standards setting bodies require to develop youth accessibility guidelines.

Future research could extend the findings of this study by exploring each of the design guidelines advanced in Section 5 in-depth. Potential research questions include: What digital scaffolds do youth who are novice AT users find helpful when learning to use new instructional technologies alongside people who do not know AT? How can non-mobile technologies emulate the simple interfaces and workflows that BLV youth appreciate? What nonvisual and visual semantics facilitate communication between BLV and sighted people using the same instructional technology? What specific supports are effective at helping teachers create accessible spatial information?

Observations of primary- and secondary-school-aged BLV youth using a variety of instructional technologies in and out of the classroom would be particularly helpful. Moreover, investigations in public school settings will be more generalizable than those in segregated educational settings (e.g., schools for the blind) since most BLV youth in the United States attend public schools.

In addition to research to understand BLV youth's digital access needs, research teams should collaborate with BLV youth and adults and employ co-design methodologies to (1) design solutions to the access barriers BLV youth face and (2) to develop technologies and curriculums to support AT literacy development. Since many youth do not get to learn AT at school, they have to cobble together learning opportunities with limited resources. One technology that may prove useful is an educational game that supports youth in (1) learning how to use nonvisual AT, (2) developing an inquiry approach to learning how to use technology, and (3) increasing their technology self-efficacy. Such a game would employ constructivist or constructionist approaches to learning [Jonassen, 1991; Papert and Harel, 1991] and immerse youth in a story, a quest, or a design challenge through which they could develop their AT knowledge.

Finally, large-scale quantitative studies of BLV youth's digital access needs would be of value. Obtaining large samples of the BLV youth population is a known challenge [Lazar et al., 2017]. However, research teams that can acquire sufficient funding, time, and relationship with public school districts may be able to bring a large-scale quantitative study to fruition.

## 8 Conclusion

For decades BLV youth have been excluded from technology-mediated learning due to the systemic inaccessibility of K-12 instructional technologies. Youth accessibility guidelines would help schools address this systemic inequity, but such guidelines do not yet exist nor does the robust knowledgebase required to write them. Together, HCI scholars, education scholars, and BLV youth can construct the knowledge required to write youth accessibility guidelines that K-12 schools can use to evaluate instructional technologies and transform the unjust status quo. I urge more HCI scholars, particularly in the United States, to take up this critical work and build on the momentum created by the Inclusive Educational Technology initiative's recent scholarship.

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