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Assistive Technology in Education

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Abstract

This chapter overviews the state of research in assistive technologies that support teaching and learning for *individuals with blindness or severe visual impairment* (IBSVI). Education, learning, and information are culturally defined and designed for efficient communication and access for humans with typical visual and spatial capabilities. Understanding the unintended roadblocks to IBSVI brought on by such culturally defined elements of instruction and information is critical to assisting IBSVI to participate in the education and learning milieux. We divide the assistive technology challenges to the support for classroom instruction and for individual access to informational media. We address different aspects of each of these challenges and discuss various approaches to these aspects.

Introduction

Imagine if everyone else were endowed like the basketball superstar Michael Jordan in his prime. What kind of a world would we live in? The entire built-up world and cultural expectations would be designed around 2 m-tall individuals with tremendous dexterity. Stairsteps would be high enough to require significant effort for most readers of this chapter to scale, shelves would be too high for us to reach, and even the dimensions of keyboards, phones, and books would concomitantly enlarged. Furthermore, interhuman interaction would be designed where we would expect to hand things to one another across larger distances (most of us would become klutzes, dropping things that are routinely handed/tossed to one another), and we would find most objects for everyday use to be too awkward heavy to handle. The authors and readers of this chapter would, in short, be “disabled” in this world.

The point of the previous paragraph is that we are *embodied beings* and that the cultural world is designed for this embodiment. *Individuals with blindness or severe visual impairment* (IBSVI) are “otherly embodied” along the dimension of visual perception. Many of the barriers faced by IBSVI arise not only from the natural world but from the cultural expectations designed into the world we construct and the means by which we communicate and inform. This is especially true for teaching and learning that are almost entirely culturally constructed and has concomitant implications for technology to support for learning. These implications extend to the understanding of the expectations built into the way we communicate concepts and design information and provide impetus for technology convergence between cultural understanding, cognitive science and interactive, multimedia, and signal processing technologies to address assistive technology needs. Furthermore, disability can be seen as a situational construction. In a noisy room, our ability to listen to a conversation may be compromised, and in low-light or under competing attentional load, our visual ability may require technological assistance.

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This chapter focuses on two general needs for teaching and learning: support for classroom instruction and support for individual access to information through reading.

Instruction and Classroom Support

Society's interest in nurturing an educated populace and workforce has, to a large part, been supported by public/government education systems. Classroom instruction is the de facto configuration for providing instruction within the public education framework. In this section, we discuss technologies that support classroom instruction and learning. We divide this discussion under three general headings: visual aids for accessing classroom presentations, instruction material, and technology aimed at the teaching of specific courses.

Access to Teaching/Learning Material

One issue faced by IBSVI in classroom situations is the need to access individual information while attending to joint instruction. Sighted students can, for example, read screen menu layouts, while the instructor is guiding the class through the use of a computer system. IBSVI students may similarly access the menu system through screen reader like the popular JAWS software but will have to receive the information either in audio or through some kind of tactile reader (we will cover tactile readers later in our general discussion on reading). For audio, covert individual access may involve the use of over-ear headphones. Technology investigations to ameliorate the problem of headphones impeding classroom speech include the use of new bone-conduction devices in conjunction with auditory graphing software that was presented by Chew and Walker (Chew and Walker 2013). The drawback to such solutions in general is that of intramodal competition where the audio channel becomes overloaded.

Another challenge faced by IBSVI in the classroom is the need to take notes in class. A solution is to have human-sighted note-taking aides take class notes for the IBSVI. Apart from the labor intensivity of such approaches, notes are typically "personal self-communication." Notes taken by someone else are not typically as useful. One approach to this problem is embodied in the note-taker project (Hayden et al. 2011) designed to support students with low vision or legal blindness in inclusive classrooms. The approach employs cameras whose focus, magnification, and tilt can be controlled by the IBSVI student who can then take notes either by typing or with a stylus. The approach also represents a more general class of screen magnifiers (including handheld optical devices) for students with residual vision. The drawback with such approaches is the competition of attentional and activity resources placed on the IBSVI student to control the camera, attend to the instruction, and take notes. Also such approaches are not usable by individuals with total blindness.

A third requirement for classroom access is that of access to graphical information that accompanies instruction. Low-cost approaches are available to produce static tactile raised-line graphics on paper using embossing processes similar to printing with dot-matrix printer capable of creating raised indents on embossable paper (e.g., https://viewplus.com/product/vp-spotdot/). Alternatives to these include the use of aural and haptic feedback using such devices as pen tablets, audible bar graphs, and force-feedback devices. Ladner and colleagues (Jayant et al. 2007a) approach the problem as one of translating visual graphics into tactile forms through analyses and reformulation that involves human workflow practices.

Support for Classroom Discourse

An important aspect of support for classroom instruction for IBSVI is that of supporting the multimodal aspects of discourse in instruction as illustrated in Fig. 1 where three channels of communication are evident: (1) the vocal presentation by the instructor, (2) the graphic that carries the mathematical concepts

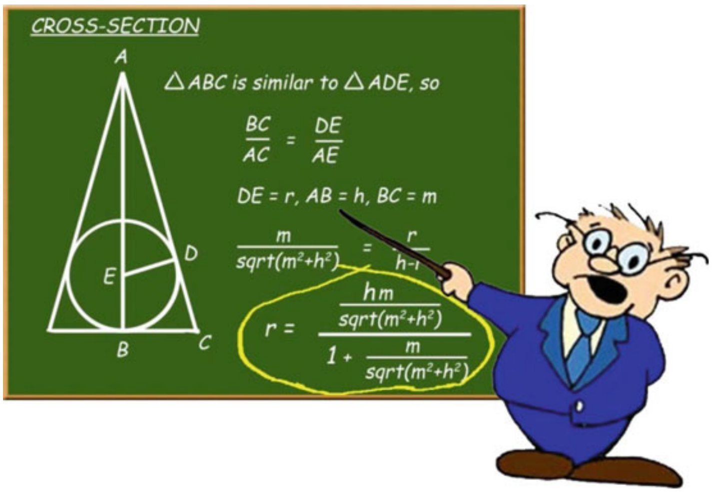

Fig. 1 Illustration of mathematics instruction

being discussed, and (3) the pointing gesture that allows the instructor and student to share a focus into the illustration co-temporally with the vocal utterance. The speech channel is not normally impeded for IBSVI, and the graphical access was address previously. Quek and Oliveira (Quek and Oliveira 2013) employ a haptic glove interface to furnish the IBSVI with awareness of the deictic gestures performed by the instructor over the graphic in conjunction with speech. They present a series of studies where they show how their Haptic Deictic System (HDS) can support learning in inclusive classrooms where IBSVI receive instruction alongside sighted students. The approach employs machine vision to track the pointing gestures of instructors into graphical presentations and the reading point of IBSVI students as they read an embossed raised-line graph that mirrors the instructors' graphics. A haptic glove with a pattern of embedded vibrotactile devices activates in real time to inform the readers where they have to move their reading point to access the points of instructional foci of their instructors. The authors show how the introduction of the HDS was advantageous to all parties: IBSVI, instructor, and sighted students. The HDS created more learning opportunities, increased mutual understanding, and promoted greater engagement. Their approach differs from others as they formulate the problem as that of situated discourse, while prior work had focused on the act of reading or acquiring information. Their discourse analysis shows that it is possible to introduce technology to mediate interactions in inclusive regular classrooms and still have the conversants focused on the lessons' objectives.

Technology Aimed at the Teaching of Specific Courses

The classroom and instructional aids discussed thus far are generally applicable to broad ranges of subject matter. In recent years, there has been the surge of technology to assist the teaching/learning of specific courses. Howard, Park, and Remy (Howard et al. 2012) used a Wii remote controller as a haptic display paired with sound feedback to convey a robot positional information to a programmer who is blind. Students found the haptic device helpful in feeling the movement of the robot; they also found the audio feedback more helpful than the haptic feedback. The addition of the haptic feedback helped blind programmers to understand the robot's actions. Mohammadi and Murray (Mohammadi and Murray 2013) developed a sound-based network packet tracker for Cisco Networking Academy and successfully tested with IBSVI pupils. The NavMol software helps students who are blind to navigate through molecular structures and chemical reactions guided by sound (Fartaria et al. 2013), enabling collaboration between blind and sighted students and their teachers in inclusive classrooms. The Musibraille software enables music composition via a version of Braille conceived for that purpose (Borges and Tomé 2014).

The application embeds a voice synthesizer and a small screen reader, and it's been used in inclusive music classes throughout Brazil, also enabling inclusive classroom collaboration.

Support for Individual Access to Information Through Reading

Support for reading is a critical segment of assistive technologies to support IBSVI in learning. We can divide the domain of reading support under five headings: (1) character-based tactile reading, (2) audiobook readers, (3) computer screen readers, (4) mathematics text, and (5) digital tactile graphics.

Character-Based Tactile Reading

Braille represents text as raised dot patterns laid out spatially on paper. Braille gives IBSVI the opportunity for self-paced reading and rereading of information on a page. The layout and spatial cues make it easy to find information and to compare data content. Modern Braille printers are able to emboss Braille documents through a simple printing process, giving individuals and institutions the ability to prepare paper-based Braille. Braille readers engage in an active process, pausing and thinking as they read; however, reading Braille requires continuous practice. A problem is that only 10 % of IBSVI in the USA can read Braille. This is because of the difficulty of learning Braille, especially for individuals with late blindness. More importantly in the USA, inclusive education where IBSVI learn alongside sighted students is mandated by law. While inclusive education addresses many social problems for IBSVI, it has the side effect of eliminating the Braille reading culture of previous schools for the blind. Furthermore, Braille books are large in size and cumbersome to handle. Amazon.com, for example, lists the print version of "Harry Potter and the Order of the Phoenix" at 870 pages and lists the Braille version as 14 volumes on thick stock paper measuring 11″ × 11.5″. A typical page has only 40 characters across and a maximum of 25 lines. This makes Braille literature unwieldy and not easily portable. This threatens to leave IBSVI behind in a growing "information divide" as the amount and rapidity of information access increase for individuals in general.

Refreshable Braille displays (RBDs) that can render tactile Braille dots provide dynamic access to text. These technologies approach the digitalization, portability, and mobility problems of Braille books; however, they eliminate the capability of Braille to provide spatial referencing because the size of the displays is relatively small. They typically feature displays with just one line of Braille text in blocks of 20, 40, or 80 characters. While reading one line at a time is not as passive as in listening to audible text, the information is still represented in temporal sequential format. The reader cannot develop a mental map of the page she reads and faces many of the text-locating problems endemic to audiobooks. At this time, RBDs are still expensive solutions for widespread use.

Various research groups worked on the idea of conveying Braille characters to IBSVI readers by vibrotactile modality using mobile and wearable devices. Piezoelectric actuators under the touchscreen of a mobile device were used for reading one Braille character at a time by generating tactile feedback. The Body-Braille (Ohtsuka et al. 2008) system uses six vibrating motors on the human's body to represent one Braille character, while UbiBraille (Nicolau et al. 2013) attaches vibration motors to six rings worn by the users around the fingers. The advantages of these vibrotactile Braille methods are that they are convenient for individuals with blindness and deafness and that they use inexpensive devices. However, they require training to be learnt by IBSVI, in addition to previous knowledge of Braille. Apart from UbiBraille that was used by two participants to read sentences, most of these systems have been demonstrated only for reading a character at a time.

Audiobook Readers

Audiobook readers are a popular solution for reading textual material because they have negligible learning curves. OCR and text-to-speech technology also provide a means to scan and read printed documents audibly. While these technologies are well suited to leisure reading and dissemination of information, the experience they enable is different from active reading, primarily because they provide no spatial access to the rendered text. Audio format provides IBSVI with information in the form of linear ephemeral stream that overloads IBSVI's working memory. A fundamental reason for this is that information is typically designed for access by sighted individuals with ability to scan material spatially. In short, information media are designed so sighted readers can scan recently read material for contextual refresh, and the information is often formulated with the implicit assumption of such capability. Because audiobooks endemically obliterate spatial layout, IBSVI are left with the tremendous cognitive load of maintaining all contextual information in memory while reading. Interviews with IBSVI who feel comfortable using both audio and Braille pointed out that audio is ideal for recreational reading, while Braille is mandatory for active reading. Abandoning Braille for audio for IBSVI, like converting print to audio for sighted population, leads to virtual illiteracy. Braille advocates stress that auditory learners must read and write, in either print or Braille, to meet the competitive employment needs.

Computer Screen Readers

Screen reading technologies constitute our third category of reading support for IBSVI. Screen readers are designed to interact with on-screen computing systems. Modern operating systems include screen reading as part of their universal access technology, e.g., Windows' Microsoft Narrator and Apple's VoiceOver. There are also popular commercial screen readers such as JAWS. This assistive technology has been extended to the touch devices, which are largely inaccessible to IBSVI. These different types of screen readers have two main functions: reading the screen content and navigating the screen. Screen readers have usability problems (Parente 2006), especially when the content of the screen is designed with the assumption that it will be visually read. Browsing web pages by IBSVI, for example, using screen readers leads to more probing and takes longer than for sighted users. Screen readers process pages sequentially, which leads to information overload. The navigation function on desktop screens is achieved by keyboard shortcuts, which are typically different combinations of two keys. On touchscreens, IBSVI can navigate the screen by touch or alternatively connect the touch device to a keyboard. Screen readers do not provide IBSVI with feedback regarding their location on the screen of both desktop and touch devices. In touch devices, the spatial awareness problem is reduced; however, much more accuracy is needed in locating place because any unintended touch could lead to undesired interaction. Finally, screen readers are not built to support active reading, and they do not provide IBSVI with the needed mental model of the page. Research on music and earcons (Asakawa et al. 2002) has addressed auditory representations for spatial layout in browsers. Changes in music were used to represent colors, thus helping the user to differentiate the context of content during navigation, and highly contrasting earcons (separate audio components such as rhythm, pitch, intensity) were used to represent text, images, and links to reduce a listener's confusion.

The main problem of accessing digital documents by IBSVI is the lack of easy access to the document structure. To address this problem, El-Glaly et al. presented STAAR system (El-Glaly et al. 2012) that combines static tactile overlay with touch slate device and audibly renders touched words, allowing the IBSVI reader to fuse spatial information from the static landmark overlay with the textual content of the page in audio. The STAAR system features a dynamic speech-touch interaction model that interprets the reading intent (estimating what the IBSVI intends to read next) to help to guide the reader to avoid straying by incorporating a "sonic gutter" that overlays sonic cues over the audio text rendering (El-Glaly and Quek 2014). Studies with the STAAR system showed that IBSVI were able to develop and maintain a mental model of the pages they read.

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Mathematics Text

Mathematic equations are translated for IBSVI to read in one of the following formats: tactile, haptic, audio, or a hybrid of these formats. The main difference between plain text and mathematics is the multidimensionality of mathematical information. Various approaches to this approach either linearize the mathematics expressions or provide renderings that attempt to preserve the spatial relationships of expressions that contain mathematical information.

An approach to linearizing mathematics expressions is by extending Braille with Nemeth code that uses the same six-dot rendering as Braille. DotsPlus is another solution that offers tactile representation for mathematical information (Barry et al. 1994). DotsPlus uses Braille for alphabets and numbers, combined with raised images. The raised images are used to represent easy to recognize symbols, e.g., plus and minus signs. The advantage of DotsPlus is its ability to keep some of the original document structure, leveraging the understandability of the reading material.

A second approach is to convey mathematics expressions in audio. MathML, for example, is an XML application that is used to describe mathematical information in addition to saving its structure. MathML could be read by special types of screen readers such as Math Genie (Gillan et al. 2004). Another technique for audibly expressing math equations is the Audio System for Technical Reading (AsTeR) (Raman 1994). This software employs a voice synthesizer and an audio sound generator to read aloud the math information. It uses different pitch voice to indicate superscript and stereo effects to read data in tables.

In Toennies et al. (2011), the authors explained how they employed a haptic touchscreen to convey mathematical information through aural and/or vibratory tactile feedback. They also conducted user studies to test the effect of using only audio, only haptic, and audio/haptic feedback. Interestingly, their results showed that both audio and haptic are valuable.

Digital Tactile Graphics

Typical science and engineering books contain different kinds of graphs such as charts and diagrams. To enable IBSVI access graphs, they are translated into tactile graphics. It was shown by studies that tactile graphs give faster and more accurate access to the data than Braille and electronic tables (Watanabe et al. 2012). This is because the tactile perception is the best modality for graphical image understanding (Gardner 2002). As discussed earlier, Ladner et al. provide an excellent discussion on the practice of the reformulating graphical material for IBSVI access through a sequence of workflow steps, e.g., scanning, tracing, and adding Braille label (Ladner et al. 2005). The first step of the process typically involves the processing of the graphical data to extract a reformulation that is amenable to tactile output. Accessibility specialists who create tactile graphics may use general image editing software such as Photoshop or CorelDraw or special software that support tactile rendering of images. Jayant et al. describe Tactile Graphics Assistant (TGA) that automates these steps to various degrees to produce a layout that can be embossed (Jayant et al. 2007b). Similarly, Wang et al. describe an approach whereby semantic image categorization and segmentation and semantic-driven image simplification are employed to reformulate documents for tactile presentation (Wang et al. 2007). For output, user studies showed that raised-line pictures were better for IBSVI in performing discrimination, identification, and comprehension (Krufka and Barner 2006). For obtaining high-quality tactile graphics, the American Foundation for the Blind published a list of characteristics of discriminability in the components of a graphic (Hasty and Presley 2006) (e.g., that lines are perceived the best if they are straight and solid). In addition to pure tactile rendering, other researchers have combined tactile and audio output for graphical rendering.

Conclusions

Much of the challenge faced by IBSVI in education and learning arises from the fact that classroom instruction and information media are culturally determined. In the classroom, the students have to have access to multiple streams of information simultaneously. They have to be able to attend to the instructor's speech, access the presentation material being used, and read the individual material relating to the instruction (e.g., an open textbook on the desk) and the embodied behavior of the instructor. Each of these elements represents opportunities for assistive technology support. For individual reading and learning, reading material and information are designed for consumption by humans with typical visual/spatial perceptual capabilities. To date, Braille that was invented in 1824 is still one of the best options to provide IBSVI access to both the spatial layout and the elemental contents (the words) of documents. Refreshable Braille arrays are still too limiting to support spatial access, and audiobooks are spatial information poor. There have been many approaches to supporting access to mathematics expressions and material as well as graphics. None of the solutions advanced thus far have fully solved these problems of access. There are many open problems yet to be addressed in assistive technologies to support teaching and learning for IBSVI that present opportunities and rationale for convergence of technologies and sciences.

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