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Engaging with information beyond vision: hands-on approaches to computational thinking for blind and visually impaired learners

Kyungwon Koh, JooYoung Seo, Si Chen, and Eugene Malcolm Cox
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Abstract

Introduction. This project develops accessible maker tools and activities to foster computational thinking (CT) skills in blind and visually impaired (BVI) learners, while investigating the experiences of two key groups: (1) BVI learners and (2) librarians and maker professionals who design and deliver accessible CT programs.

Methods. The pilot phase designed and delivered an accessible electronics and coding curriculum to three BVI youth in a two-day summer camp. Data was collected through two debrief focus groups—one with BVI learners and one with the maker professionals who served as instructors.

Analysis. All interviews were recorded and transcribed. The research team used a grounded theory approach to analyse the interview data.

Results. Both learners and instructors highlighted the benefits of tactile and multi-sensory learning tools, though challenges emerged with the text-based coding platform. Learners self-reported increased confidence, autonomy, and interest in CT skills. Instructors adapted their approaches with detailed verbal descriptions and modifications to tools and lesson plans. Understanding the diverse needs of BVI learners and providing personalized assistance was crucial.

Conclusion. Tactile and physical approaches to computational thinking show promise for previously marginalized learners, though challenges remain. Future research will explore how emerging technologies, including AI, can further enhance accessibility for BVI learners.

Introduction

In contemporary culture, information is predominantly received and produced visually, whether through text, graphics, or videos. Learning resources and environments, including those in STEM fields, are no exception, which often marginalizes individuals who are blind or visually impaired. The participation of blind and visually impaired (BVI) individuals in STEM (Science, Technology, Engineering, and Math) fields has been notably limited (Beck-Winchatz & Riccobono, 2008). Among the many barriers that they face, existing computational thinking tools, particularly text-based programming environments, pose frequent accessibility challenges for BVI learners. For instance, screen readers may struggle to interpret code, and navigation via keyboard shortcuts is often inadequate. Similarly, block-based programming languages, such as Scratch or Blockly, rely on visual interfaces, making them largely inaccessible to BVI learners.

Traditional learning environments often rely heavily on visual information, but learning can be experienced through multiple senses, benefiting not only the BVI population but all learners. A hands-on approach, for instance, enables learners to create meaning and solve problems by interacting with tangible objects and technologies. In this project, we leverage hands-on learning in makerspaces—often referred to as '*maker learning*' or '*learning by making*', rooted in Seymour Papert's (1993) Constructionism—to engage BVI learners through its physical, tactile, and multimodal nature.

The goal of this project is to foster computational thinking (CT) skills in BVI youth, supporting their sense of agency, introducing STEM mindsets, and expanding career opportunities through maker learning. As Wing (2006) describes, CT is a universally applicable skill set and mindset for everyone, not just computer scientists, involving problem-solving, system design, and understanding human behavior by drawing on core computer science concepts (p. 33).

Ultimately, this project aims to create more inclusive and accessible learning environments for BVI learners and beyond. It is one of the few research projects conducted by, with, and for BVI learners, involving both blind and sighted researchers in *collaborative interdependence* (Bennett et al., 2018). The asset-based approach emphasizes the non-visual strategies and sensory abilities of blind individuals, such as touch, hearing, smell, and residual low vision, as central assets. Our blind researchers and participants play a pivotal role in leveraging these strengths to realize the full potential of multimodal learning, moving beyond vision-dominant tools and approaches to foster more accessible information, and learning environments for people of all abilities.

Research design

This research develops accessible maker tools and activities to foster computational thinking (CT) skills in BVI learners, while exploring the experiences of two key groups: (1) BVI learners and (2) librarians and maker professionals who design and deliver accessible computational thinking programs. This paper reports on the pilot phase, where the team delivered an accessible electronics and coding curriculum to three BVI youth in a two-day summer camp. Data was analysed from two debrief focus groups—one with BVI learners and one with maker professionals who served as instructors.

Tangible coding and electronics curriculum development

The accessible computational thinking program was co-designed by the research team, which included university researchers (one blind, one sighted) and graduate assistants, as well as three maker professionals (experienced coding instructors but new to teaching BVI learners). We created lesson plans around physical coding and electronics tools like Code Jumper, Snapino, and Snap Circuits, while adapting existing lessons to be more accessible for BVI youth. The activities focused on key concepts like circuits, coding loops, and conditional statements. The lessons emphasized developing skills in tinkering, debugging, and collaboration, with a strong focus on tactile and auditory learning.

In hardware-focused activities, learners assembled circuits—including series and parallel—while exploring concepts like electrical flow, resistance, current, and voltage. Software activities using Code Jumper introduced programming basics by creating physical code sequences, encouraging both individual tinkering and group learning. The integration of hardware and software in tasks like using Arduino with Braille labels and Visual Studio Code allowed learners to apply coding concepts hands-on, using auditory and tactile feedback to enhance understanding, while visual elements were included but not essential.

Study setting, participants, and data collection and analysis

In August 2023, a two-day summer camp was held at the Chicago Lighthouse, an organization serving individuals who are blind, visually impaired, and disabled. The project team developed an accessible website and promotional materials in both braille and large print, with the Chicago Lighthouse supporting distribution and recruitment through their marketing tools. The University Institutional Review Board approved the project. Three blind or low-vision youth (2 males, 1 female, aged 15-20) participated in the camp, which included lessons on coding with Code Jumper, electronics with Snap Circuits, and hardware-software prototyping with Snapino. Instructors led the lessons, while researchers assisted as needed and conducted field observations.

After the camp, the research team conducted a focus group interview with each participant and instructor group. Each interview lasted approximately an hour and a half. All interviews were recorded and transcribed. The researchers conducted grounded theory approach to analyse the interview data.

Tables 1 and 2 below show information about the participating learners and instructors.

Learner Pseudonyms	Age	Race	Gender	BVI	Education
Imran	20	Asian/Pacific Islander	Male	Visually Impaired	College
Lilac	15	White/Caucasian	Female	Blind	High School
Isaac	15	White/Caucasian	Male	Blind	High School

Table 1. Demographic information of teen participants

Instructor Pseudonyms	Age	Race	Gender	CT Teaching Experience	BVI Teaching Experiences
Susan	36	White/Caucasian	Female	10 Years	None
David	30	White/Caucasian	Male	8 Years	None
Wyatt	28	Black/African American	Male	7 Years	None

Table 2. Demographic information of makerspace professionals

Findings and discussion

The findings present initial analyses from the pilot study, highlighting key insights into the experiences and perspectives of both BVI learners and instructors, along with instructional recommendations.

Effectiveness of the tactile and multi-sensory learning tools

Both learners and instructors noted that hands-on tools like Snap Circuit and Code Jumper enhanced learners' understanding of computational and electronic concepts. Overall, participants reported positive experiences with Snap Circuit and Code Jumper, while encountering challenges with Snapino. Snap Circuit helped make abstract concepts more tangible, and the use of a grid system with coordinate-based instructions further supported spatial understanding. Participants found this system particularly helpful for assembling circuits and understanding their functionality: "The braille and coordinates helped me understand how the fan worked. I've heard of using coordinates for chess but never with technology before."

> *Working with the circuits, I came to figure out the basics: positive, negative, current, the flow, and…resistance… Circuit was good, and we also did the music thing. I also learned that we can use the circuit and connect with the computer so we can manage the power, how much you want to send on the circuit… These were totally new to me. I didn't know any of them before. I did some coding in high school, but it was all on the computer, nothing physical. In this section, I guess it was practical. I could see what was happening physically. That was great. Things make more sense when you see them happening in physical form.*

Code Jumper helped learners grasp coding concepts by enabling them to '*feel*' how virtual codes are mapped onto physical block-based pods, each representing a specific function. This tactile interaction was useful for understanding the sequence and dependency relationships between different functions. Participants remarked:

each new peg—pause, loop, plus, minus—was interesting. The physical cords helped me understand how everything connected; Having the physical cords and being able to tell how they're all connected, until there are too many pods to keep track of, really helped me understand. Each time we introduced a new element, like the pause or the loop and the different little pegs you plug in with X or plus/minus, those were really interesting.

On the other hand, both learners and instructors reported challenges with the Snapino lesson taught on the second day, which was intended to build on the more engaging and playful learning experiences from the first day with Snap Circuits and Code Jumper. Snapino, a hardware kit that integrates Snap Circuits with the Arduino platform, allows users to work with both physical electronic components and programmable code (hardware-software integration).

However, teaching the program in the Arduino programming environment—a text-based coding platform—within a short period of time seemed to result in cognitive overload. Troubleshooting and debugging with the keyboard and screen reader were particularly difficult for participants. Debugging requires navigating the complex coding interface and using shortcuts, which were not fully covered in a brief, verbal-only session. While sighted participants can intuitively explore the user interface and interpret error messages visually, this same exploration posed significant challenges for BLV learners.

Learner confidence, autonomy, and interest

The self-reported learner focus group data highlight some of the key outcomes: increased confidence, autonomy, and interest. A participant who had previously had a negative experience learning about circuits in a group setting at school mentioned that, with the use of braille and coordinate-based instructions, they were now able to understand how the circuit worked. The learner explained that their previous experience with computational thinking was not positive because their learning independence had been overshadowed by other sighted learners.

> *My teammates just did it for me because I didn't know what to do. Since it's a group activity, I couldn't really feel what was going on. I can't just touch it was going so fast. I could not just be like, 'Hold on, let me check it out by touching it.' They're just like, 'okay, we're going to do it.' Then it was just pretty confusing. Then there was a little quiz, and I was just like, 'I have no idea.' That was hard. But this time, I really liked that everything was described tactically, and nobody stepped in and took over or just did it for me...*
>
> *A lot of times I feel like people just take over, whether I'm doing a craft or whatever, they'll just be like, 'Oh, it looks like you're struggling over there.' Then they just do it. But then I wouldn't be able to put it together myself, so I really liked being able to put it together myself.*

Supporting learners' autonomy by providing tactile materials, hands-on guidance, and ample time for exploration appears to be an effective strategy.

Even though learners found the Snapino lesson quite challenging, a learner reported positive emotions, which fostered an interest in future learning. They expressed increased interest in coding after discovering the potential of using a keyboard and other assistive technologies for programming:

> *I feel like it's [Snapino] really cool that we got to use it on a real computer, and even though I wasn't very good at it, I think it just allowed me to see it is possible, which was really, really good. But I was a little bit too much of a beginner to actually problem-solve anything, so I just had somebody help me. But it was cool to see that you can use JAWS to read the code, and then use all those keystrokes to move around.*

Instructor challenges and strategies: verbal descriptions, adaptations, and personalized assistant

The participating instructors had extensive experience teaching STEM topics in informal learning environments, particularly in makerspaces, but they were new to teaching the BVI population. Prior to the camp, the project team, led by a blind researcher, provided a series of professional development sessions on accessibility. In multiple design sessions, including mock teaching role plays, the instructors wore blindfolds to better understand the challenges that BVI learners might encounter.

One of the major adaptations for instructors when transitioning from teaching sighted learners to BVI learners involved the extensive use of verbal descriptions. Instructors emphasized that verbal descriptions must be detailed, specific, and include tactile sensory information. They also suggested the use of analogies and metaphors to enhance understanding. These descriptions should precisely convey shapes, positions, and functions to assist BVI learners in identifying, navigating, and interacting with objects and their components. During the focus group, instructors noted the complexity and length of explaining Snapino to the BVI teens, which took approximately 10 minutes.

Instead of saying 'Grab ***this*** *from your kit', you had to say 'Reach into the power bag, you're going to* ***feel around*** *for a* ***thicker*** *wire that's got a square end at one side and a* ***rectangular*** *end at one side. That rectangular* ***end is going to go into your computer****, make sure that this* ***part goes down*** *and the hollow end* ***goes up****, the square end is going to go into* ***the large metal*** *portion'.*

The instructors reported a learning curve in developing the skill to describe concepts and objects clearly and accurately without relying on visual references or awareness. They also noted the high cognitive demand placed on BVI learners, who had to remember complex instructions and spatial information. This required instructors to be especially mindful of their teaching pace and the complexity of their explanations, maintaining a balance between the number of descriptions given and the level of detail provided. Suggestions include using tactile teaching materials, such as tactile references to support self-guided navigation of the user interface and code. Supplementary learning materials could be created with a swell form machine to present the tangible layout of the user interface and code structure. Additionally, 3D shapes and references could be employed to further enhance understanding.

Finally, instructor focus group data emphasized the importance of understanding and accommodating the diverse needs of BVI learners. These learners have varying abilities, and what works for one may not work for another, requiring tailored approaches. Even within the small group of three learners, there were distinct needs. One learner had limited vision, braille literacy, and no additional disabilities. Another was completely blind and faced additional challenges, including mobility issues with assembling small components. The third learner had low vision, could read larger fonts, but had no braille literacy.

The instructors adapted their teaching in real time as challenges arose. For instance, during the Snap Circuit lesson, an instructor noticed that a learner with some vision, but no braille literacy was struggling to keep track of grid locations and made on-the-fly adjustments:

on the second day, I noticed he was struggling because [, without braille literacy,] he had to count and memorize grid locations. I gave him a new board with large letters, and it made a huge difference.

With a one-on-one instructor-learner ratio and real-time adjustments, the team was able to provide personalised assistance during the camp. However, challenges are anticipated in larger learning environments where such individualized support may not be as feasible.

Conclusion and future direction

This paper has demonstrated how tangible, accessible Maker tools like Code Jumper, Snap Circuits, and Snapino can be integrated into a coding and electronics curriculum through an initial analysis of the pilot study. The research team continues to analyse data collected during the camps, including pre- and post-survey responses, observation data, and triangulation with focus group data. The program tested in the camp has since been distributed to multiple public libraries and museum makerspaces. Two of these makerspaces engaged their local BVI learners, and we conducted interviews with the librarians who implemented the program. Ongoing data analysis aims to provide insights into multimodal learning and information processing, as well as efforts to sustain, improve, and disseminate the program more broadly.

While the pilot program shows promise and demonstrates the effectiveness of tangible coding platforms, a significant challenge remains in translating the skills acquired through these tools into text-based coding environments. Future work will explore how natural language processing and AI-powered programming assistants, such as GitHub Co-pilot, can help visually impaired individuals reduce unnecessary cognitive load. This '*speak-to-code*' approach may allow them to focus on core computational thinking processes rather than grappling with visual and textual interfaces. Additionally, emerging AI technologies, like 'Be My AI', are supporting BVI individuals by describing visual items in everyday settings. Future research will investigate how such technologies can further reduce barriers for previously marginalized learners.

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About the authors

Dr. Kyungwon Koh is an Associate Professor in the School of Information Sciences and the Director of the Champaign-Urbana Community Fab Lab at the University of Illinois at Urbana-Champaign, USA. She received her Ph.D. from Florida State University, and Her research expertise includes Library and Information Sciences, with a focus on youth services, learning, and community engagement; information behavior and literacies; and the maker movement in libraries. Contact email: kkoh@illinois.edu

Dr. JooYoung Seo is an Assistant Professor at the School of Information Sciences, University of Illinois Urbana-Champaign. He earned his Ph.D. from Penn State University, and his research focuses on accessible computing, inclusive STEM education, and multimodal data representation. Contact email: jseo1005@illinois.edu.

Dr. Si Chen is a Postdoctoral Researcher at the Lucy Family Institute for Data and Society and Notre Dame Learning at the University of Notre Dame, USA. She received her Ph.D. in information sciences from the University of Illinois Urbana-Champaign in 2024. Her research expertise lies in artificial intelligence in education and human-computer interaction, with a focus on how emerging technologies influence educational equity and accessibility through human-centered approaches. Contact email: schen34@nd.edu

Eugene Cox is a PhD student in Informatics at the University of Illinois at Urbana-Champaign. Their research interests include collaborative learning, learning sciences, and the use of technology to support collaborative learning. Their dissertation explores how secondary mathematics teachers use video clips to reflect on responsive teaching practices in middle school mathematics classrooms. Contact email: emcox3@illinois.edu

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