Coding Through Touch: Exploring and Re-Designing Tactile Making Activities with Learners with Visual Dis/abilities

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Abstract: Learners with dis/abilities are still often marginalized when it comes to learning with contemporary maker technologies, despite efforts to broaden participation. The purpose of this study is (1) to explore the experiences of diverse learners with visual impairments engaging with a tactile block-based maker / robotic coding kit; and (2) to discuss how to better engage such learners in the maker ethos through technologies and activities with different affordances. Interaction analysis was conducted on a three-day summer making workshop for high school students and pre-collegiate adults with visual dis/abilities to understand their experiences both with and without accessibility modifications. Findings as well as recommendations for increasing the accessibility of current maker tools and activities are provided to assist educators and designers in understanding more inclusive ways to embrace diverse learners in making.

Introduction

With recent advancements in the affordability of maker and DIY tools, content creation technologies have become more accessible for novices and children than ever before (e.g., Halverson & Sheridan, 2014). Ever since early efforts to broaden youth access to computational and mathematical literacy (e.g., Papert, 1980), research continues to demonstrate how constructionist technologies can help people learn and engage in computing, design thinking, visual memory, and interdisciplinary content knowledge (e.g., McNerney, 2004; Sullivan, Elkin, & Bers, 2015). Many have further noted their benefits to computational thinking (Wing, 2008), or the application of concepts, practices and processes derived from computer science to solve complex problems.

Robotics platforms have been praised for their ability to make coding tangible and embodied in the physical world in ways that are more accessible for children to apply to their mental models of existing structures (Papert, 1980); for example, children can visualize how a LOGO Turtle would interpret lines of code and embody those structures in their own actions when troubleshooting (McNerney, 2004; Papert, 1980). As a result, robotics platforms, such as LEGO Mindstorms, have had a legacy of successful implementation in formal learning. Researchers have extended this early work through the development of tangible programming bricks (McNerney, 2004) and physical programming blocks that facilitate robotics coding by utilizing material structures that are familiar and accessible to young learners (Sullivan, Elkin, & Bers, 2015).

However, despite notable advances, accessibility for learners with dis/abilities has been mostly neglected (Brady, Salas, Nuriddin, Rodgers, & Subramaniam, 2014). Learners with dis/abilities, in general, have had limited access to the maker movement, along with opportunities to engage in a host of relevant 21st century skills. In other words, and in the vein of this year's conference theme on interdisciplinarity and deepening conversations in the learning sciences, we explore an iterative, participatory design activity aimed at broadening inclusivity in making and coding for diverse learners with dis/abilities. This paper details a pilot robotics-based maker workshop for high school youth and young adult learners with visual impairments. We examined the following research questions: How do learners with visual impairments engage in coding and making activities that are tangibly accessible through a robotics platform? How does the accessibility of the tools affect learners' individual and collaborative interactions? What design elements do participants express would be beneficial for equitable learning and collaboration?

Background

There are two lines of research that underpin our work: learning opportunities provided through content creation, and pedagogical and design efforts to broaden the participation of underrepresented groups. Early efforts to engage learners in mathematical learning and computing focused on broadening the novice accessibility and applicability of computational models and tools (Papert, 1980). The Maker Movement was largely inspired by and resulted from work demonstrating the capacity for constructionist learning through computational toolkits and fabrication tools on a lexicon of applied curricular skills that had been lost as K-12 and collegiate education started favoring conceptual knowledge. As scholars expanded their view, so too did ideas about computational literacy, and, instead, started to put forth a definition of "computational thinking" (Wing, 2006), which included conceptual knowledge (i.e., coding structures), along with practices (ways to apply that knowledge) and perspectives (ways of viewing computing in broader social and cultural contexts that included oneself).

Several scholars have engaged in efforts to broaden the participation of groups underrepresented in STEM. For instance, Buechley, Eisenberg, Catchen, and Crockett (2008) found that e-textiles engaged girls and others typically not attracted to coding and engineering, with the integration of sewing, design, and circuitry, and Buchholz and colleagues (2014) focusing on the historical roots of STEM gender inequity, found that e-textiles empowered girls in part because of long standing gendered assumptions. The introduction of e-textiles in a collegiate hackathon both increased the number of female participants, and found that participants across gender expressed better appreciation of the diversity of computing practices (Richard, Kafai, Adleberg & Telhan, 2015). Scholars have also found that e-textiles can serve to bridge coding and indigenous cultural practices (e.g., Kafai, Searle, Martinez & Brayboy, 2014). Taking a step further, Richard and colleagues (e.g., Richard & Giri, 2017) found that the combination of multiple toolkits with different "material affordances" served to encourage more inclusive design teams, and to shift diverse youths' self-efficacy and collaborative learning through making and coding. Such studies show that purposeful implementation of diverse toolkits along with the design of the learning activities could meaningfully combine several disciplines, and generate new learning and design cultures.

Many learning scientists have highlighted the complexity involved in learning through cultural practice and the importance of using cultural diversity as an educational and research design asset (e.g., Richard & Giri, 2017; Scott, Sheridan & Clark, 2015). We leverage these approaches in our framework, which pushes the field to consider accessibility along with equity and inclusivity in design and research (Fig. 1).

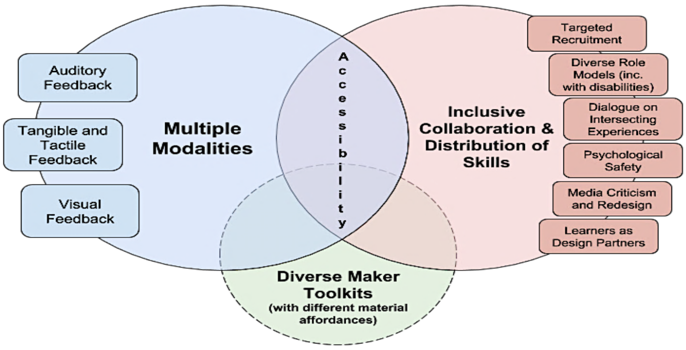

Figure 1. Our equity, inclusivity and accessibility framework.

Conceptual framework: Equity, inclusivity and accessibility

We anchor the literature on equity and inclusivity within a holistic inclusive framework that considers accessibility. While a variety of definitions are used to describe design that ensures accessibility and equal opportunities for all, the most commonly used is "Universal Design" (UD) (Mace, 1985). The seven principles of universal design have prompted the development of other frameworks, such as Universal Design for Learning (Rose, 2000).

The literature on inclusive makerspaces underscores that the design of tools and environments can have a great influence on how learners position themselves. There are three areas borrowed from Universal Design for Learning (UDL) principles, which cut across the literature on equity and inclusivity in making and computing, that we focus in our framework: (1) multiple means of representation, (2) multiple means of expression, and (3) multiple means of engagement. Culturally responsive computing, while primarily suggested for diverse gender and racial/ ethnic inclusion (Scott, Sheridan & Clark, 2015), assimilates all three UDL areas by emphasizing the need for diverse and anti-stereotypical representation in advertising, diverse mentors involved in program activities, psychologically safe learning spaces, and activities that involve inter-cultural dialogue, as well as critique and redesign of media and technologies so they are more culturally representative (Seo & Richard, 2018; Richard & Giri, 2017).

In addition to the ways that design decisions around equity and inclusivity are complementary to UD, there are specific design affordances that have been suggested to be more accessible for learners with disabilities: auditory feedback, visual feedback, and tangible or tactile feedback. In an effort to create an accessible maker learning event at a public library, Brady and colleagues (2014) were purposeful in implementing different maker toolkits in ways that could be accessible through auditory feedback, finding that the modifications allowed learners with visual impairments to engage with the exhibits. Similarly, Born (2015) utilized LittleBits - a plug-and-play suite of magnetic circuits, sensors and actuators - to design audio-based counters for learners with visual impairments. Similar kinds of modifications could be made to other maker toolkits directly to help learners with visual dis/abilities create design solutions and other projects of interest, instead of engaging as passive users of products created by others. By creating both a larger base for the LittleBits kits, and light responsive feedback, Hollinworth and colleagues (2014) found that learners with physical and learning dis/abilities were better able to engage on their own and with others. Tangible and tactile feedback can be especially helpful for learners with low vision and learning disabilities, such as dyslexia, for which reading instructions can be especially challenging.

Methods

With these areas of needed emphasis in mind, we turn our attention to this study, which explores how learners with varying visual dis/abilities engaged in computational thinking and design, individually and collaboratively.

Table 1: A summary table of the study participants

Pseudonym	Group	Visual Acuity	Braille	Age	Race	Day1	Day2	Day3
Aaron	A	Severe vision impairment	No	19	Black	Yes	Yes	Yes
Evie	A	Moderate vision impairment	No	18	White	Yes	Yes	No
Matthew	B	Blind	Yes	17	White	Yes	Yes	Yes
Mary	B	Blind	Yes	16	White	Yes	No	Yes
Stella	B	Severe vision impairment	No	16	White	No	Yes	Yes

Participants and setting

Participants (see Table 1) in this study were high school students and pre-collegiate young adults (aged 15 through 19) attending a two-week summer institute on college preparedness for learners with dis/abilities in a rural section of the Northeastern US. The study took place in July 2017 during a three-day making workshop offered as an optional activity. Each session lasted between 1-1.5 hours over the 3-day period. Five of the nine participants completed all informed consent requirements. The nine participants were divided into two groups: A (*N*=4) and B (*N*=5). We identified participants' visual acuity based on their survey self-identification as compared to the four World Health Organization classifications (WHO, 2018). All names have been changed to protect confidentiality.

Figure 2. Arranging coding blocks (left); Scanning to program KIBO (right). Images from kinderlabrobotics.com.

Maker/Robotics learning tool

The workshop utilized KIBO during the activities. KIBO (Kinder Lab, 2017) is a wooden robotics platform (Fig. 2) designed to teach young learners (ages 4-7) core programming concepts through play. Learners can add different modules, such as "clap/sound" sensors shaped like ears, distance sensors shaped like telescopes, and actuators, such as lights, to the robot base. They would then code it to perform actions with wooden coding blocks that are scanned into the robot (Fig. 2). Each block represents different programming actions or concepts, such as "begin/end," "move forward," or "repeat until" receiving an action (such as a sound). Despite its classification as a platform for early childhood learners, KIBO selection was supported by research demonstrating the accessibility of its auditory, visual and tactile features: the physical coding blocks enabled easy manipulation and some tactile feedback, and the scanning function provided auditory feedback and some visual feedback through its bright light.

Activity design

On the first day, KIBO kits were distributed to each group without any accessibility modifications in order to (1) understand how learners with visual impairments interact with the default kit, and (2) collaboratively redesign the activities with the participants. Participants were prompted to think about and discuss opportunities and challenges, and to engage in design recommendations. On days 2 and 3, two accessibility modifications were made: (1) braille labels were added to each of the programming blocks; and (2) an organizing system using three different plastic containers (i.e., input/sensor group; output/actuator group; and condition/loop group) was provided to assist with block finding. Day 2 focused on basic coding functions and day 3 engaged learners in more advanced interactions.

Data collection instruments and procedures

Participants engaged in think aloud activities throughout (Lewis, 1982) and focus group interviews at the end of each session. They also completed pre- and post-surveys, providing (1) demographics; (2) visual acuity; (3) answers to seven open-ended questions on prior making and coding experiences, and (4) perceptions around making and coding. Activities and interviews were videotaped and transcribed for verbal and non-verbal interactions.

Data analysis

While multiple data sources were collected, we primarily report on the learning activities (including think alouds) and group interviews. We captured the activities with multiple cameras (up to 3 per day), which totaled over 9 hours of video data. We utilized interaction analysis (Jordan & Henderson, 1995), as follows: first, the two authors of this paper took detailed content logs, which included annotations of each event; second, we conducted "Interaction Analysis Laboratory (IAL)" sessions where we reviewed and discussed the video footage with trained graduate assistants on the team ($N = 3$) to identify thematic areas of salience; third, we transcribed the verbal and non-verbal interactions and individually reviewed the videos and the transcripts to triangulate and enrich interpretations; and, finally, we both worked together to mutually cross-check and integrate all of the processes into one holistic narrative.

Findings

Day1: During the first day, we focused on giving participants an opportunity to interact with KIBO in an unstructured way, and read the instructions on how to use it, which were printed in both large print and in braille.

Figure 3. Group B: (a) Mary (right) asking her teammate to describe a coding block; (b) Matthew (left) asking to describe two blocks he put together; (c) Mary touching the sequence; (d) teammate (middle) scanning a block.

Group B: Three participants made up group B: Mary, Matthew, and a non-consented participant (herein referred to as "teammate") who self-identified as having a moderate vision impairment. Once they were given the KIBO for the open-ended activity, Mary and Matthew seemed to rely on their teammate who appeared to have the strongest visual acuity amongst them, as illustrated during their first few minutes orienting themselves to KIBO:

Mary: What is this? *[feels the purple colored block and extends it to her teammate (fig. 3a)]*

Teammate: Oh, that's wait for clap. So, if we clap, like, it'll wait until we clap. *[motions a clapping gesture.]*

Mary looks intently in the direction of her teammate and the block as they speak then touches the KIBO.

Matthew: What's this? Does it go side to side? *[Matthew shows two blocks he connected together (fig. 3b)]*

Teammate: Turn right and turn left, yeah. *[describing the block depiction]* So, you wanna use that?

Matthew watches as the teammate explains then gets distracted by a cell phone. He motions his head but does not answer verbally as she takes the blocks and adds them to the sequence.

Teammate: Okay. *[she acknowledges adding Matthews blocks.]* So… um, end if… *[pulls out another block.]*

Mary: So, we might wanna put clap at the end. *[leans in and pushes KIBO forward while speaking]*

Teammate: Yeah. *[arranges the code, adding the clap and end if blocks to the end of the sequence.]*

The teammate explains the sequence: beep, shake, go forward, go backward and end if clap.

Mary: Are there any more blocks you wanna add? *[pulls blocks from the bin.]*

Matthew: Make it light up. *[pulls blocks from the bin.]*

Teammate: Where's the KIBO? Yeah, where's the KIBO itself?

Research Assistant (off-camera): This one. *[points to the KIBO]*

Teammate: Oh…Ok. That makes sense! *[looks at the robot body next to Mary, reaches out and picks it up.]*

Mary: I think we have to scan each of these. *[Mary runs her hands across the sequence (fig. 3c).]*

The teammate scans each block in while the others look in the direction of the scanning sound (fig. 3d). When it came to scanning in the coding blocks, both Mary and Matthew remained peripheral, observing or listening to their teammate, in part due to accessibility limitations. During the middle of the first day, when we asked Mary what she was working on, she answered: “Right now we're having to use one of us with vision.” During the small group interview, both Mary and Matthew found scanning to be the most challenging and suggested design modifications. Mary suggested, “it'd be nice to have a marker around where the scanner is.” Matthew suggested having a raised area by the bar code so that it would be easier to independently identify and scan coding blocks through touch. However, throughout, they both attempted to fully engage, and the group followed Mary’s suggestions, which helped enable them to successfully program a sequence of actions.

<u>Group A</u>: Aaron, Evie, and another (non-consented) participant, who self-identified as completely blind, made up Group A. Once the KIBO and instructions were provided, all group members first attempted to figure out how it worked by reading the instructions. Aaron preferred reading the large print guidelines while Evie gravitated to the default instruction card provided by the company, finding the strong orange and white contrasted backgrounds and text amenable. Afterward, they tried to assemble the robot body, which consisted of actuators (i.e., four wheels; its joint motors; and light bulb) and sensors (i.e., distance; “clap/sound” detector; and light detector). The KIBO they received, unfortunately, had faulty batteries and did not function appropriately at first. As soon as she finished reading the manual, Evie took a very active and hands-on role with the KIBO. First, she immediately reached out her hands to explore KIBO’s blocks, then started reading each block by bringing it close to her line of vision and using her partial sight. Aaron also tried to figure out how to use KIBO by reading some of the blocks on and off; however, he primarily focused on assisting the (non-consented) blind group member in activities such as looking for batteries and working collaboratively to assemble the robot. While they initially made a few attempts, KIBO’s initial functional difficulties appeared to have a disengaging effect for Aaron and his teammate, who started to joke around.

When a working KIBO set was introduced by the facilitators about 10 minutes into the activity, the group began to start programming. However, their group work was disjointed. Evie took over scanning while Aaron read out instructions based on the manual (at her request). In response to a question from one of the instructors (Author 1) asking why she was taking on the scanning role, she said: “Because it was easier for me. It'd probably be easier for me than [our blind teammate] and plus it'd be more confusing for me [than him] because I don't have as much experience with building things.” She both acknowledged how her visual acuity might work as an asset for her team, as well as her non-consented teammates’ self-identified proficiency with building things such as model cars. While Evie and Aaron noted their teammates’ skills, it is only Aaron who made a direct attempt to engage him in the activities, whereas Evie focuses on her individual engagement in relation to the group.

<u>Day2:</u> The second day involved significantly more structure, with a 15-minute introduction by Author 1 on how to program and integrate sensors, actuators, and conditionals/loops. Afterward, each group was then asked to complete the following four missions throughout the activity: make KIBO (1) go forward and sing a song, (2) go forward, turn right and spin three times, (3) sing a song when the light is off, and (4) start when you clap and go forward until it meets something. On day 2, we also revised the KIBO with greater accessibility options. However, due to time constraints, we were unable to integrate all of the design suggestions, such as tactile scanner modifications. Instead, we added two accessibility considerations: (1) braille labels on each KIBO block; and (2) three plastic containers that sorted and distinguished the inputs/sensors, outputs/actuators, and conditional/loops.

<u>Group A:</u> There were three individuals on day 2: Aaron and two non-consented teammates. Aaron took on the scanning role in Evie’s absence, and employed auditory feedback as supplementary sensory information while repeatedly lining up the coding sequence and scanning in the blocks. At one point, he asked, “Can [KIBO] talk and scan at the top?” Despite his efforts, KIBO’s inherent scanning inconsistencies made it difficult to have a mastery experience despite correctly lining up the code. In his post-survey and interview, Aaron expressed that scanning was the most challenging, and that modifications were needed to identify the scanning area.

<u>Group B:</u> There were two newcomers: Stella, who self-identified as having a severe visual impairment, and a non-consented participant who identified as completely blind. Mary missed this session so it was only Matthew who was able to read braille and compare between the two days. The most discernible change noted was that Matthew began to be more engaged in the group when compared to day 1. Instead of either asking or observing others’ actions to find coding blocks, he began to independently explore each piece in braille. However, this did not necessarily lead to a more active role, as he continued to hand off components to others with better functional vision, rather than affixing them to the KIBO himself, although he demonstrated the ability to do so utilizing tactile feedback. He also continued to avoid scanning. Stella, who had better functional vision than Matthew, worked as a problem solver. When the group was prompted during mission 3 to "make KIBO sing a song when a light is off," she actively exchanged her coding sequence ideas with other members: “Should we do ‘if’ before we do ‘sing’? Do we have to do this - 'if light' like how we have if it's dark it sings?” Her think-aloud reflects how

accurately she engaged with the concepts introduced earlier that day. When the group worked on mission 4, she guided the group where they need to put an obstacle. Similar to Matthew, she left the scanning job to the teammate with better visual acuity. However, she handed her each block to scan and took the lead when coding the actions.

Day 3 focused on predesigned activities that would encourage more complex coding, which involved three missions on race tracks setup for each group (see fig. 4). The first mission involved making KIBO move by clapping from the start to point A, singing a song one time, moving forward until near point A, and turning right.

Figure 4. Day 3 racing activity: (Left) Teams at their identical race tracks; (Right) the primary instructor (also blind) demonstrates how to tactually measure the shape of the track.

Group B: Mary, Matthew, Stella, and their teammate engaged in the race competition. This was the first time Mary experienced the redesigned activities, and she was now able to read the coding blocks independently. This appeared to change the group dynamics, as she no longer needed to ask what the blocks were. When the group first tried to get their robot to sing and move forward to point A, it would only sing. Their teammate realized they were missing the distance sensor (telescope) and added the part, but it still did not perform the desired actions.

Figure 5. Group B: (a) Mary points to the coding blocks; (b) Mary rearranges the sequence; (c) the teammate questions the sequence; (d) the teammate tests out the KIBO; (e) the teammate points out it does not work.

Mary: You have to go forward before the repeat.

Teammate: No because-that's like a comma around it… it's gonna repeat until its near. It's gonna go forward.

Mary: But that's gonna repeat the sound… You're having it repeat the sound until- *[points to the blocks (fig.5a)]*

They continue to disagree about the code, and Stella interjects to explain the repeat until sequence.

Stella: When you're coding something, you're giving it this specific action.

The teammate tries to start the KIBO again but it is not performing the intended actions.

Research Assistant (RA): Okay, so, what is the problem? It sings, but it does not go forward so ...

Mary: Because it does not forward program at first. May I please do it…?

Mary takes the forward block out from between the repeat blocks and places it before them (fig.5b). The teammate points at the repeat blocks and then makes a questioning gesture (fig.5c).

Teammate: … There's nothing between the parenthesis now though. So, it's just gonna, what is it repeating…? I don't know if that's right. *[picks up the KIBO and starts scanning.]* We could try…

The teammate scans the new sequence: begin, sing, forward, repeat until near, end repeat, turn right, end. She places the KIBO on the track and presses begin (fig.5d). It goes forward a few inches then stops.

Teammate: *[looks toward Mary and points at the KIBO (fig.5e)]* See?

Mary: Something's wrong … May I scan? *[reaches for the KIBO but the teammate starts examining it.]*

Teammate: Hm… the scanner is…? *[waves hands in front of it]*

RA: …Yesterday you guys did some action where it would-once you did something, it would sing. Right?

Teammate: Clap. We need the clap action! *[makes clapping gesture]*

The teammate adds the new block to the sequence. After a few minutes of discussion, she reads it aloud.

Teammate: [Mary] wanted to change the code to see if it would work better. So, we have begin, sing, forward, repeat until near, end repeat, turn right, end… I don't really think that's right.

Mary and the teammate continue talking and moving blocks around (fig.6a). They try to scan several times but the scanner makes error sounds. Author 1 comes by and asks them to confirm their code.

Teammate: So, we have begin, wait for clap, sing, repeat until near, forward, end repeat, turn right, end.

JY (Author 1): That's right. That's right.

Teammate: Maybe it's just the [KIBO] body… Yeah, like I know this is the right code…

Figure 6. Group B: (a) Mary and the teammate rearrange the sequence; (b) the team gets a new KIBO; (c) Group B tests their new sequence; (d) Group B cheers when it works successfully.

The group is given a new KIBO robot base. Mary helps reassemble the wheel and motor on the new KIBO (fig. 6b). The teammate scans in the sequence and then places the KIBO at the start of the track (fig. 6c) before clapping to start their program. It sings before proceeding down the track. Once it reaches point A, where a bag is placed, it turns right. They all begin clapping and cheering at having successfully completed the first mission (fig. 6d).

Despite some challenging interpersonal dynamics, the group was able to collaboratively contribute to solving the first mission. Though Mary's initial modifications to the sequence were not technically correct, it is more important to note how the simple accessibility modifications repositioned her collaborative group identity over time. In response to the post survey question on what she thought she learned or didn't learn from the making experience, she said, "you can't do the flashing lights without the light bulb… you need to do the process [and] to do the programming," revealing her engagement in computational thinking practices. At the end of the workshop, Matthew expressed his feeling about the experience: "It was different to try out all the different tasks and basically use critical thinking to try to work as a team to figure out the situation… [this] helped a lot." Stella also described her experiences positively: "I've actually never coded before but I really liked the feeling when we figured how to light up the code and watch the robot actually do it properly… I think it was very easy to understand the format just having the building blocks that you can stick together rather than having to write anything down."

Group A: Aaron was the only consented participant present on the last day. Aaron started by handing the KIBO to one of the non-consented group members who could see better than him to scan what he programmed. Unfortunately, KIBO's actions did not correspond to what Aaron had intended. Aaron began to debug his code by vocalizing it out loud: "Repeat it and make it go forward again. It would begin, sing, repeat forward, end repeat and turn right and then end." During his vocalizations, he missed two components: a conditional block ("Wait for Clap") and a loop parameter ("until near"). Because he had an "until" block instead of an "until near" block, his KIBO responded to a forever loop that he did not intend. One of the students in group B came to help him fix the code after a few unsuccessful attempts. They first tried to see if there were any hardware issues, then they found some missing coding blocks. In contrast to the first day, Aaron was actively engaged in the hands-on activity and attempted to keep solving the problems collaboratively with others. At the end of the activity, Aaron expressed his learning experience as follows: "I didn't understand it at first. I had trouble when I was reading the directions… But as we started programming the robot, I started understanding what we were doing." When asked what was most challenging, he said: "I think getting KIBO to scan the code."

Discussion and conclusion

Despite its tangible capabilities, without modifications, KIBO did demonstrate some limitations for learners with visual impairments to independently engage in core activities such as block finding and scanning. This was not specifically due to inherent difficulties with the scanning functionality, which actually was noted regardless of age or ability (in fact, in 2018, KinderLab released larger barcodes on each block and new functionality to rectify the issue). In many ways, KIBO featured many affordances over existing maker technologies, such as easy manipulation and multimodal feedback. We found that learners with varying visual acuity were able to engage in building activities, such as adding sensors and actuators, but we also found that different levels of accessibility affected how learners positioned themselves within the learning activities. We also found interesting differences between groups and individuals. For example, although Aaron had higher visual acuity than most, he self-selected to remain a peripheral observer at the onset. After adding some accessibility modifications, we discovered other affordances and limitations. For instance, Matthew and Mary who were both braille readers, benefitted from its inclusion, and began to engage more independently. Furthermore, Mary's re-positioning within the group provoked more collaborative discussion and negotiation. However, accessible design features are not always universal. For example, Aaron struggled to take advantage of the braille modifications because: (1) he couldn't read braille; and (2) he found scanning the KIBO, which we did not modify, more challenging than block identification. On the other hand, increased exposure seemed to expand his agency, which he leveraged to engage fellow learners collaboratively. Though we engaged in some level of participatory design, as well as utilized auditory, tactile, and visual feedback, as designed on KIBO, along with additional tactile and organizational elements, our findings highlight that a more flexible approach may more effectively engage learners with a diverse range of experiences and abilities. Future iterations will work more closely with participants as design partners and incorporate a wider variety of suggested features.

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