Awareness in Collaborative Mixed-Visual Ability Tangible Programming Activities

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Figure 1: Three pairs of children engaging during the sessions

Abstract

In the context of computational thinking tasks, which often require problem-solving and critical thinking skills, awareness of a partner's actions can play a significant role in fostering a balanced collaboration. Understanding how awareness influences mixed-visual ability group collaboration in a tangible environment can provide insights into inclusive design for learning environments. To address this issue, we ran a user study where 6 mixed-visual ability pairs engaged in a tangible programming activity. The study had three experimental conditions, representing 3 different levels of awareness. Our findings reveal that while pre-existing power dynamics heavily influenced collaboration, workspace awareness feedback was essential in fostering engagement and improving communication for both children. This paper highlights the need for designing inclusive collaborative programming systems that account for workspace awareness and individual abilities, offering insights into more effective and balanced collaborative environments.

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CCS Concepts

• **Human-centered computing** → **Accessibility systems and tools**; **Accessibility technologies**; **Collaborative and social computing systems and tools**.

Keywords

Accessibility, Mixed-Visual Ability, Collaboration, Computational Thinking

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1 Introduction

Collaboration plays a significant role in our lives from early childhood classrooms to professional environments. Collaborative learning has considerable advantages in educational settings while improving overall academic results [3]. Within the Computational Thinking domain, collaborative tasks require high levels of interaction, workspace awareness, problem-solving, and critical thinking skills, which also foster social-emotional development in children [3].

In recent years, there has been a growing interest in supporting collaboration among children with mixed visual abilities within accessible computational thinking environments [31, 43, 50]. Previous studies have explored how technology can mediate interactions, promote engagement, and encourage inclusive behaviors [33, 43, 55]. These environments often leverage multisensory programming environments incorporating sound and tactile elements, such as storytelling and robots to engage children and support diverse abilities. However, while such tools help facilitate interaction, they also introduce new challenges, particularly in maintaining awareness of each other's actions and contributions among children with different visual abilities [48].

Workspace awareness is the real-time knowledge of each participant's actions and intentions within a shared environment [15], which is key in ensuring coordinated and engaged participation in collaborative tasks. Effective workspace awareness allows participants to anticipate each other's actions, align their contributions, and provide mutual support, ultimately leading to more inclusive and productive teamwork. Despite its recognized importance, there is limited research on its benefits and challenges within programming environments in the context of children with mixed visual abilities.

This study addresses this gap by investigating how different levels of workspace awareness impact group dynamics in collaborative programming tasks among children with and without visual impairments. Specifically, we explore how varying levels of auditory feedback, ranging from no awareness cues to private and shared awareness cues, affect children's engagement, participation, and interaction quality during a tangible programming task. Our research question is: *How does workspace awareness shape group dynamics in a collaborative programming task among children with and without visual impairments?*.

We conducted a user study with six mixed-visual ability dyads. The children worked together on programming a toio [1] robot to navigate mazes using tangible coding blocks under the three distinct workspace awareness conditions. By adjusting the auditory feedback on real-time knowledge of the participants and the robot's actions, we aimed to identify the optimal balance of information that fosters balanced participation and effective collaboration.

Our findings highlight the importance of workspace awareness in maintaining engagement and promoting active participation in collaborative tasks. We also reflect on the role that interpersonal dynamics, such as the children's personalities and their understanding of each other's strengths and limitations, play by shaping group interactions. In this paper, we contribute insights emphasizing the importance of designing collaborative programming systems that account for individual abilities and facilitate equitable participation and communication to enhance overall collaborative experiences, particularly for children with mixed visual abilities. By actively mediating these interpersonal dynamics, technology can help prevent one child from dominating the interaction, fostering a more inclusive and balanced collaborative experience.

2 Related Work

Considering our goal of exploring how workspace awareness shapes group dynamics in a collaborative programming task among children with and without visual impairments, we will first review related work on existing inclusive programming tools. This will be followed by examining previous studies on collaboration in mixed-visual ability contexts and their challenges. Finally, we will delve into the current literature on the impact of awareness on group dynamics.

2.1 Inclusive Programming Environments

Learning computational thinking (CT) at an early age promotes computational literacy and fosters the development of critical, cognitive, and social skills [57, 58]. As a result, there has been a growing effort to include introductory coding environments, such as Scratch and Blockly, in educational settings [18, 24, 46]. These mainstream coding kits have been shown to reduce cognitive load, develop agency, and enhance creativity and learning [3, 18, 53]. However, despite their benefits, these mainstream coding environments often present challenges for children with disabilities, particularly those with visual impairments, due to their heavy reliance on visual elements. [5, 16, 24, 30, 44].

A recent shift towards integrating multimodal elements into coding kits holds significant potential for creating inclusive learning spaces [9, 16, 29]. These solutions explore auditory and haptic feedback to make text-based and block-based programming languages accessible to children with blindness or visual impairment (BVI) [16]. Tangibles and robots have proven valuable tools to create inclusive programming environments [31, 33, 36, 48, 50]. These tangible CT kits enhance traceability and debugging by providing physical coding elements that are easier to manipulate and understand. For example, StoryBlocks and Torino are tangible block-based games that allow novice programmers with BVI to program and create audio stories [22]. Similarly, ACCembly and TACTOPI are tangible environments designed to foster inclusive collaborative experiences while interacting with a robot, enabling children with and without visual impairments to work together [31, 49]. Furthermore, because these kits are designed with accessibility in mind they have the

[1] https://www.sony.com/en/SonyInfo/design/stories/toio/

potential to facilitate pair-programming and cooperative activities [31, 50], in co-located and remote settings [48].

2.2 Mixed Visual-Ability Collaboration

In the field of human-computer interaction, there has been a growing interest in developing technologies to improve mixed-ability collaboration, particularly in collaboration between sighted individuals and those with BVI [59]. Designing collaboration tools for mixed-visual ability settings has its challenges. How can the group communicate in a way that is accessible to all members? What role should technology play? Or even in which scenarios and applications can these tools be most beneficial?

Collaboration and alignment in group settings are often streamlined through visual cues, such as head nods to indicate agreement, eye-gaze to focus on specific topics, or turn-taking signaled by looking at the next contributor [33]. However, alternative modalities are essential when designing technology for mixed-visual ability groups. These new communication methods must ensure that all participants, regardless of their visual ability, can actively participate, understand the group's progress, contribute effectively, and avoid cognitive overload. [2, 10, 23].

For instance, sound has successfully facilitated communication and collaboration during code reviews in mixed-visual ability pairs [45]. Additionally, tangibles and robots have also proven valuable in enabling successful collaboration between children with and without visual impairments in activities related to computational thinking, decision-making, and design [31, 33, 36, 48, 50].

Technology can also support collaboration while each group member explores different goals [2]. Collaboration can serve as a means for facilitating learning activities and enabling accessible communication for children [55], or it can be an end in itself, fostering social development opportunities [33, 34]. Technological approaches can assign roles tailored to each group member's abilities. For example, in a game designed for mixed-visual ability pairs, assigning asymmetric roles based on each player's visual capabilities led to engaging and collaborative experiences for both participants [14].

Prior research has explored the potential of technology in collaborative settings for mixed-visual ability children [31, 33, 34, 36, 48, 50]. While these studies highlight the benefits of multisensory and robotic environments it remains unclear if the degree of awareness provided by these approaches influenced children's collaboration dynamics.

2.3 Workspace Awareness in Collaboration

Awareness is essential for collaborative work and must be maintained across space and time [15]. It includes understanding how everyone feels, where they are, and what actions are being performed, were performed, or people intend to perform [11, 51]. In real-time activities like pair programming, collaboration requires additional synchronicity between peers, making awareness critical and time-demanding [45].

Awareness influences collaboration and impacts each group member's sense of participation and contribution, which is crucial for achieving shared intentionality among participants [54]. If awareness is imbalanced among group members, it can lead to reduced collaboration, unequal opportunities, limited contributions, and diminished agency [45]. Therefore, it is vital to ensure that awareness is equally accessible to all participants, regardless of their visual abilities. However, in mixed-visual ability groups, achieving this balance is challenging, as sighted members naturally have an advantage in visually perceiving the environment and others. In this context, technologies often employ nonvisual modalities.

Tangible objects can be a potential solution as everyone can perceive them. Tangibles allow participants to access tactile information during activities and facilitate sharing and communication with others [12, 27, 42]. Through tangible representations, children, with and without visual impairment, can track the status of play (leading to awareness) and share common entry and access points (leading to shareability), both of which are vital for collaboration [55, 56]. However, tangible information alone may not provide equal and synchronous access to peers' actions in mixed-visual ability pair programming activities [48].

Audio is another modality that has shown promise to increase workspace and group awareness fostering group effectiveness [7]. For example, in a document-editing solution for blind users, earcons were used to enhance group awareness by communicating background events, identifying collaborators using different voice fonts, and using spatial audio to convey editing location [25]. In a code-review activity involving mixed-visual ability groups, audio-based assistive technology effectively informed participants of each other's actions, allowing the group to focus more on the task and less on creating a shared awareness space of each other's actions [45]. Similarly, in a treasure-hunt activity involving visually impaired participants, a robot that provided audio information about the peer's location enhanced the overall efficiency of the task. However, this also decreased collaboration as the task became more guidance-focused [7]. These findings [7, 48] collectively suggest that it is crucial to balance the levels of awareness and carefully select which information should be shared, as too much or too little awareness can negatively impact both the activity and group collaboration.

Our study builds on previous research focused on mixed-visual ability children's group activities using tangible coding blocks and robots to facilitate peer actions in collaborative settings. While these studies explored the use of physical objects to promote inclusion and collaboration, they did not fully investigate the impact of varying levels of workspace awareness on participation dynamics. Our research extends this work by incorporating audio cues in a tangible environment to explore different levels of workspace awareness, aiming to foster engagement and participation between children with BVI and sighted children. This approach addresses the gap in understanding how awareness affects group dynamics and task execution in inclusive programming activities.

3 Understanding the Role of Workspace Awareness on Collaboration

We conducted a user study to explore how distinct levels of auditory feedback regarding workspace awareness influence children's engagement, participation, and interaction quality in a tangible collaborative programming task.

3.1 Programming Kit

Considering existing research on accessible programming tools, we used a mainstream robot and tangible coding blocks for this study [9, 43, 48]. Following accessible design guidelines, we created a fully tangible environment for children to train CT skills by programming the robot to navigate the mazes. The pair shared the entire workspace, including one *toio* robot, a single maze at a time, a LEGO-based programming area, one speaker, and identical sets of coding blocks for each child 2.

Previous research has shown that block-based syntax allows children to concentrate on code construction while reducing cognitive load and improving fine motor skills [5, 46]. Building on this work, we used LEGO-based tangible blocks with 3D caps featuring embossed textures and shapes [6]. Each block represents a different action the robot can perform, such as moving in four directions (forward, left, right, backward), dancing, or speaking. Additionally, there are two more blocks with a *flic* button on top that trigger actions: the *play* block that initiates the robot's execution of the instructions on the programming area; and the *on demand* block that triggers the reading of the blocks in the programming area. The programming area consisted of a LEGO baseplate where children arranged the sequence of instructions using the LEGO-based blocks.

Above the programming area, a webcam was positioned to recognize the coding blocks and their order, sending the instructions to the robot. The *toio* robot, a small white cube with wheels was modified for accessibility by adding eyes and a tail to distinguish its front from its back. The robot also has an LED light on the bottom and minimal sound (e.g., turning on bip). We used the grid maps from the *toio* kit as the base to construct mazes, with colorful LEGO pieces serving as walls and obstacles. The robot's ability to recognize its position on the grid enhanced accessibility by providing auditory feedback on its location and identifying obstacles (e.g., saying "Oh oh, I can't go this way" when encountering a wall).

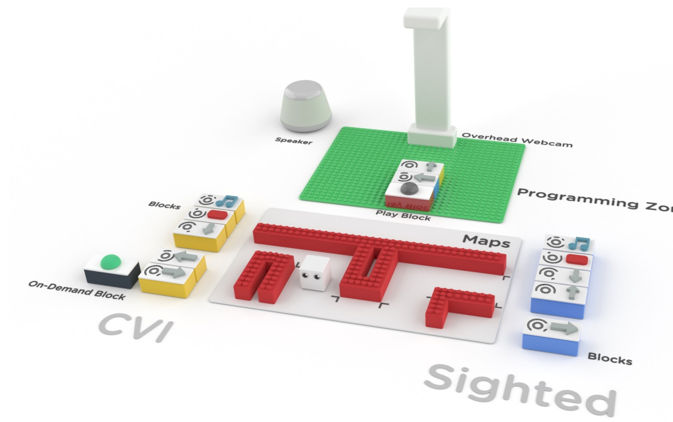

Figure 2: Setup of the shared programming area

3.2 Solving the Maze

A common approach in introductory CT activities involves children guiding a character through a maze with static or moving obstacles to develop CT skills, particularly algorithmic thinking [21]. In our study, we designed six mazes of identical difficulty that required only directional instructions (forward, left, right, backward). To challenge their spatial awareness and promote the development of orientation and perspective-taking skills—-particularly important for children with visual impairments—-we intentionally designed the game from an allocentric perspective [7].

As children tackled each maze, they had the opportunity to apply computational concepts, including data collection, problem-solving, debugging, and algorithmic thinking. The children collaborated to solve each maze by either instructing the robot step-by-step or creating a sequence of coding blocks to navigate the maze while avoiding the walls. The task was collaborative, with no defined roles, allowing both participants to contribute equally by placing blocks and monitoring the robot's movements.

4 User Study

To address our research questions, we conducted a user study with six mixed-visual ability dyads, where each pair consisted of one child with BVI and one sighted child. Each pair participated in three sessions, each in a condition designed to explore different levels of workspace awareness. For all sessions, we selected two mazes for the children to engage with using the previously described tangible programming environment. The six mazes were randomly assigned to each pair across the different conditions.

As highlighted in previous research [7, 25, 45, 48], audio-based solutions have shown promise in promoting balanced participation and enhancing workspace awareness and collaboration. However, achieving the right balance of auditory information is crucial– too little can cause confusion, while too much may lead to cognitive overload and reduced engagement. In our study, we addressed this challenge by manipulating the key variable of audio feedback regarding the actions performed by participants, designed to provide varying levels of workspace awareness:

No Awareness: Both children heard auditory feedback *beeps* through the speaker every time the system recognized blocks in the programming area or when they pressed the play button. This auditory feedback was present in the other two conditions as well.

Private Awareness: The child with BVI received audio feedback through a single earphone. This feedback included announcements of both their own and their partner's block placements in the programming area (e.g., "Block to move forward"), with distinct voices used to differentiate who placed the blocks. They also received feedback on the robot's actions (e.g., "I'm moving left").

Shared Awareness: Both children received the same audio feedback through a shared speaker, including announcements of placed blocks (e.g., "Block to move forward") and the robot's actions (e.g., "I'm moving left"), similar to the private awareness condition.

Our institution's ethics committee approved the research protocol, and the children's legal guardians signed consent forms. All children verbally consented to participate and were informed they could quit anytime. All the sessions were video and audio recorded.

4.1 Procedure

The study followed a within-subjects design, with each pair solving two mazes under each of the three conditions across separate sessions. Each session lasted approximately 35 minutes. Two researchers were present to manage the setup, guide the children, and ensure the smooth running of the activity. The children were seated side-by-side in front of the shared workspace with the programming area and kit previously described.

Upon arrival, the children were guided to the table by the researchers, who then explained the activity. Each session began with a training maze, where a researcher provided support to familiarize the children with the specific condition. After completing the collaborative activity with the two mazes, each child individually answered a questionnaire with the assistance of a researcher, which took approximately 5 minutes.

4.2 Participants

We recruited 12 children (6 with BVI), 7 girls and 5 boys between the ages of 6 and 8 (M=7.08, SD=0.65), all enrolled in 1st to 3rd grade. We asked teachers to select pairs from the same classroom. We asked participants about their age, school grade, familiarity with each other, and previous robotic or coding experience. Five children reported having previous robotic coding experience (3 with BVI, 2 sighted). Teachers also provided information about children's visual acuity, categorized into four levels based on professional diagnoses [37]. Children self-reported their familiarity with their partner on a 6-point scale (M =3.33, SD =1.15), from (0) we don't know each other, to (5) we play together even outside of school. Table 1 describes the groups' demographics. The participants' identification throughout the paper will be in the form of group number and visual ability (e.g., C1-BVI and G1-S).

4.3 Data Analysis

The video recordings from the sessions were subject to a thematic analysis. Two researchers (one who participated in the sessions) led this analysis, following the codebook thematic analysis method outlined by Braun and Clarke. The initial codebook drew upon previous work, centered on workspace awareness and information exchange [28], cooperation strategies [52], engagement and participation behaviors [1, 50].

After familiarizing themselves with the videos, the two researchers started a structured coding procedure, mixing inductive and deductive [4], as well as semantic and latent coding. Each coder proceeded to independently code all of the videos, using shared sheet documents to capture relevant instances with timestamps, codes, participants, and notes (e.g., quotes from participants or relevant behaviors). To ensure reliability and promote discussion, coders reviewed each other's coding, taking additional notes and marking disagreements, and then met to discuss and resolve these. After the coding process, they met to identify trends and patterns across the data, reaching an outline of themes. The two researchers then did another round of qualitative video analysis focused on the defined themes. The team met to discuss and finalize the themes that we present in the next section.

We focused on an in-depth qualitative analysis of behaviors rather than inferential quantitative analysis, as our goal was to understand how workspace awareness influences group dynamics. Although all groups completed the task within the proposed 35-minute session with minimal guidance, analyzing task completion rates or CT learning outcomes would not meaningfully reflect the behaviors or interactions of the participants and their sense of contribution.

5 Findings

Our study involved a small yet diverse sample of groups, each displaying unique collaborative dynamics. To ensure that the contextual details of these dynamics are not lost, we present our findings on a case-by-case basis, analyzing each pair's behavior across the three study conditions. This approach allows us to highlight the individual collaboration patterns, particularly how varying levels of workspace awareness influenced key aspects of their interaction and engagement during the programming activity. Following the individual case reports, we provide a cross-case analysis to identify overarching themes.

It is important to note that all groups successfully completed the proposed tasks and effectively applied CT concepts, with task completion times remaining consistent across conditions. In the *No Awareness* condition, tasks were completed in $M = 9:36, SD = 3:31$; in the *Private Awareness* condition in $M = 9:44, SD = 2:24$; and in the *Shared Awareness* condition in $M = 9:32, SD = 5:56$. Children reported feeling competent during the activities, with the lowest mean observed in the *No Awareness* condition in a 7-point scale ($M = 6.17, SD = 1.58$). Across all conditions, participants perceived the activities as collaborative and recognized their contributions as meaningful ($M = 3.64, SD = 0.72$, in a 5-point scale).

5.1 Group 1 - Tension Between Play and Progress

The G1 pair displayed a focused and collaborative approach throughout the conditions. They established a turn-taking dynamic from the first session and maintained a primarily balanced pace with C1-S waiting for his partner. This collaboration was particularly evident in both the shared and private conditions, with both participants actively involved, though in different ways. Despite the challenges and fluctuating dynamics, both participants reported feeling they were collaborating meaningfully and contributing to the activity's progress, expressing a sense of competence. However, differences in engagement and approach, particularly in the *No Awareness* condition, led to power imbalances and occasional frustration.

In the *No Awareness* condition, both children experienced reduced awareness of the other's actions, notably for C1-BVI, who had less perception of what blocks were being placed. This lack of awareness sometimes forced them to pay more attention to what the robot was doing. However, it led to more errors and repetitions of those same errors. For example, the C1-S was instructing the robot based on his perspective and not the robot's perspective, which caused him to be disoriented by the robot's continuous forward movement, making him question: "Why is the robot just moving forward?". The lack of awareness led to moments of confusion, such as when the C1-S did not understand why the robot did not move during a system bug situation. This led to moments where C1-S

Group	Gender	Age	Visual Ability	Coding Exp	Familiarity	Condition Order
G1	F	7	HVI	No	(2) Classmates	P, S, NoA
	M	7	Sighted	No		
G2	F	6	Blind	No	(2) Classmates	P, S, NoA
	M	6	Sighted	No		
G3	M	7	Blind	Yes	(4) Play together a lot	S, NoA, P
	F	7	Sighted	No		
G4	M	8	HVI	No	(3) Play together sometimes	NoA, P, S
	F	7	Sighted	No		
G5	F	7	MVI	No	(4) Play together a lot	NoA, P, S
	F	7	Sighted	No		
G6	M	8	Blind	Yes	(5) Play together even outside of school	NoA, S, P
	F	8	Sighted	No		

Table 1: Participating groups details, including gender, age, visual ability (High, Medium, and Low visual impairment, or Blind), previous coding/robotic experience, reported familiarity, and condition order (Private, Shared, or No Awareness).

attempted to "cheat" by manually adjusting the robot's orientation when the block he placed did not work as expected. This condition also highlighted differences in engagement. C1-S was focused on solving the challenge efficiently; nevertheless, he waited and allowed the partner to explore the map and even instructed her to place blocks, such as "Put yours to move forward". In contrast, C1-BVI placed more dancing and speaking blocks with the movement instructions ("Now it's me. I want it to say hello" or "I am gonna make it dance. I like to dance"), creating moments of engagement and fun for both participants. Occasionally, C1-S's task-focused approach conflicted with C1-BVI's playful experimentation, leading to tension, particularly when C1-BVI diverted her attention and disengaged from solving the task, creating new physical barriers for the robot or experimenting with blocks. This behavior led to visible frustration for C1-S, who felt interrupted and took over the task, even moving his partner's blocks out of reach in the programming area.

The *Private Awareness* condition started with C1-S not understanding why C1-BVI had extra blocks and the earphone. This created feelings of exclusion, with C1-S asking, "Where's mine? (said 4x) Why does [C1-BVI] have one of those, and I don't?", to which the researcher had to explain that only C1-BVI had an extra button. In this condition, C1-BVI seemed more focused on listening to the cues before and after placing a block. She looked attentive to the information provided through the earphone multiple times, waiting silently for the instructions received. Despite having access to auditory information, C1-BVI did not use it to facilitate collaboration or help guide the task.

In the *Shared Awareness* condition, there were noticeable changes in their interaction. C1-S expressed admiration and surprise at hearing the audio feedback, such as when he reacted to the system announcing:"Oh, oh, I cannot go this way", immediately understanding and changing the block, contrary to the *No Awareness*. This condition seemed to increase the C1-S's awareness of immediate and potential mistakes. In one situation, the robot needed to go the the left side. However, C1-S places the forward button in the programming area. The system announced "Block to move forward", and C1-S reacted with an enigmatic face when promptly understood that a "move forward" block would cause the robot to fall off the board. This anticipation of the commands was not perceived in advance in the other conditions. Both children appeared more engaged in this condition, as they could hear each other's actions and intentions, creating a more synchronized collaboration. Interestingly, the system saying out loud which action was being performed created a situation where, upon realizing her mistake, C1-BVI looked at C1-S with a smile, acknowledging that he, too, was aware of the error due to the shared verbal feedback. In this condition, C1-BVI demonstrated increased awareness and expectation of verbal instructions from the system. During a technical issue, where the system failed to indicate all blocks placed in the programming area, there was noticeable confusion for C1-BVI. This led to C1-BVI asking C1-S "Did you take mine?" This interaction illustrates that she was relying on auditory input to confirm their actions.

5.2 Group 2 - Speed vs. Understanding

Pair G2 presented a great disparity in their paces and approach strategy across sessions. C2-S reacted quickly to understanding the task and placing the first blocks to start programming the challenge and overall adopted a rapid *trial-and-error* strategy, frequently placing blocks and making adjustments. In contrast, C2-BVI engaged in more thorough physical map exploration and data collection before acting and giving suggestions.

In the *No Awareness* condition, C2-S approach led to his confusion more often than in the other two conditions. When the robot did not move as expected, he would express his frustration verbally, saying "What?" and "Hum?" and pressing the play block repeatedly, expecting different results. He also often looked to the researcher for guidance because the robot's actions did not align with his expectations. Meanwhile, C2-BVI, who often made correct suggestions for the progress of the activity and was aware of the obstacles given the position of the robot, was unaware of her partner's actions. Since no auditory feedback was provided, she relied on physically exploring the map, and in one instance, when C2-S placed a backward block and pressed play, C2-BVI was surprised by the robot's movement and remarked,"It moved on its own", unaware that her partner had programmed the movement.

In the *Private Awareness* condition, where only C2-BVI received audio feedback through an earphone, she became more engaged in the task. For example, after exploring the map and receiving the auditory feedback, she was able to tell her partner, "It can't go there" referring to the wall on the side of the robot. C2-BVI clear workspace awareness was also evident in the *Shared Awareness* condition, demonstrated by interpreting the audio feedback and providing suggestions. She would offer instructions such as, "No, it has a wall" and "Now you have to go righ" anticipating the next moves for the robot. However, despite her increased awareness and relay of information, C2-BVI struggled to keep up with C2-S's fast-paced *trial-and-error* method. Although she attempted to place blocks, C2-S often acted before she could contribute, making it difficult for her to fully participate in the shared environment. In several instances, C2-BVI would hear the feedback on her partner's block placement and then repeat it while searching in her set for the block to place in the programming area. However, C2-S would say "Wait!" or "It's already done" and push her hand away.

In the *Shared Awareness* condition, where both children received the same auditory feedback, C2-BVI did not attempt to place any moving blocks, likely because of C2-S's dominant role during the task. C2-S used the same strategy of rapid block placement while reacting to the audio cues to adjust his strategy. Despite C2-BVI's accurate feedback and suggestions, C2-S frequently ignored her input, undermining cooperation between the two. In one instance, C2-S even removed the dance block placed by C2-BVI from the programming area, ensuring only his block was executed. This lack of cooperation frustrated C2-BVI, especially when her block was disregarded, as she was disappointed that the robot did not perform the dance action she had programmed. The auditory cues, however, remained crucial for C2-BVI's engagement, as they provided her with awareness of the ongoing actions and maintained her enthusiasm for the task, even when her contributions were overlooked.

5.3 Group 3 - Taking Over to Not be Taken Over

The pair G3 exhibited a clear power imbalance, with C3-BVI dominating the collaborative tasks. Initially, the pair displayed a playful approach, whispering and laughing together. However, as the sessions progressed, C3-S expressed progressive facial and body language dissatisfaction with the lack of cooperation, and feeling interrupted and excluded from the activity. This shift was further highlighted in her questionnaire responses, where she reported that the activity did not feel inclusive, and they were not both participating equally.

In terms of CT, the pair mainly relied on *trial and error* to guide the robot, giving instructions by placing one block at a time. They often diverted from productivity to engage with speaking and dancing blocks, creating engagement moments for both. This was particularly evident in the *Shared Awareness* condition, where their laughter and close interaction reflected moments of shared joy, especially during their first session, where both sequenced the two dance blocks. Additionally, when they instructed the robot incorrectly, they laughed together, and C3-S affectionately grabbed C3-BVI's hand as if sharing the mistake. As the sessions progressed, it became evident that C3-BVI adopted a more controlling approach, and C3-S felt sidelined. This dynamic started with the children assuming asymmetric roles: C3-S determined the blocks to use, while C3-BVI placed them in the programming area and pressed play to send instructions to the robot. While both demonstrated awareness of the task's progress—such as C3-BVI tactically exploring the map to understand the robot's behavior—C3-BVI's dominant behavior disrupted the balance of participation. C3-BVI's actions became gradually more possessive, such as using his left arm as a barrier to control access to the programming area, pushing C3-S's hand away, and issuing commands like "give it (to me) now" and "take it off (the block that belonged to her)". This behavior led to a pattern of limiting C3-S's participation, with C3-S expressing frustration, particularly when her attempts to contribute were met with resistance or refusal from C3-BVI.

In the *No Awareness* condition, both children struggled with understanding the robot's actions and each other's contributions. C3-BVI remained focused on the robot, closely observing its movements, but the lack of feedback led to repeated errors. C3-S had the visual advantage, asking C3-BVI, "What are you doing? It cannot go forward", This situation happened when C3-BVI did not realize the robot could not go forward, but the command instructed by C3-BVI was "forward". The absence of auditory feedback resulted in several repeated mistakes, both children tried incorrect actions multiple times because there was not any indication from the robot that it was the wrong move. At one point, C3-S's frustration grew as she stated, "This (block) does not speak. These blocks don't speak." stressing the lack of feedback in contrast with the shared condition, and the challenge of coordinating actions without awareness. The lack of feedback also contributed to C3-BVI's dominant behavior as he had to be extra tactile to be aware. For instance in one situation, although the robot was moving forward, C3-BVI had to check and understand through touch where the eyes were to know where the robot was headed and whether it was moving forward.

In the *Private Awareness* condition, there was a perceptible shift in the interaction dynamics. Multiple times, C3-S frequently asked C3-BVI for clarification, such as, "What is that (block)?" This was happening because C3-BVI's hands covered the blocks and play button, obstructing her view, due to his defensive behavior. C3-S tried to engage playfully by placing a block and asking, "Guess which one it is?" to which C3-BVI responded correctly. However, C3-BVI did not tell C3-S how he knew the answer. C3-S continued to express frustration over her limited visibility and engagement, asking C3-BVI to move his hand so she could see the blocks. The system cues occasionally helped correct mistakes, but only to C3-BVI. Upon one error, where the robot should have gone left and not right, C3-BVI changed the block immediately, avoiding repeating the same error or clicking multiple times on the play button, as seen in the *No Awareness* condition. For one time, C3-BVI said what he heard, "Oh, oh, I cannot go this way," but it did not necessarily serve to inform the C3-S. In this condition, C3-BVI continued to dominate by relying on auditory cues without sharing this information, causing ongoing tension and reduced collaboration. At one point, C3-S asked, "What is the earphone telling you?" to which C3-BVI responded that the earphone was saying: "I am moving forward". Curiously, C3-BVI was using C3-S as audio input before selecting the blocks, and using the earphone to confirm the block or understand if the robot was moving correctly. He often asked her which block was which before placing the blocks in the programming area.

In the *Shared Awareness* condition, there were moments of improved coordination and shared understanding. For example, when the robot announced, "Oh, oh, I cannot go this way", both children immediately recognized and corrected the mistake, often exchanging a quick glance and swiftly swapping the block. This rapid response contrasts with the *No Awareness* condition, where they repeatedly made the same error without realizing it or understanding if it was wrong. In comparison, during the *Private Awareness* condition, only the C3-BVI child could quickly identify and correct mistakes, while the C3-S remained less informed about the errors. This shared feedback facilitated quicker adjustments and reduced some of the trial-and-error frustration observed in the other conditions. However, despite these improvements, C3-BVI's defensive behavior persisted, such as keeping his hands in front of the blocks, and he continued to dominate the interaction. Interestingly, in this condition, C3-S did not ask for clarification, like "What (block) did you put?" or "Move your hand so I can see", since she could hear the verbal cue for the block being placed. Nevertheless, C3-BVI's obstructive behavior sometimes hindered the camera that detected the blocks, leading to situations where C3-S neither saw nor heard the block because the system could not detect it. This continued to contribute to C3-S's sense of exclusion and dissatisfaction, stressing that while *Shared Awareness* cues helped with task engagement, they did not fully mitigate the underlying power dynamics and control exerted by C3-BVI.

5.4 Group 4 - Assumed Turn-Taking

Pair G4 adopted a turn-based approach throughout all three conditions, where each child patiently waited for their partner to place the blocks. Although they didn't explicitly communicate whose turn it was, their coordination was obvious, and they avoided getting in each other's way. Across all conditions, they consistently thought out loud, corrected mistakes together, and offered suggestions, with levels of communication and the fluidity of their turns varying.

In the *No Awareness* condition, the pair took more time to understand the robot's actions and plan the next steps. C4-BVI often relied on his partner or the researchers to recognize progress and determine the following actions. Without auditory cues, both children had to explore the map visually and tactically to gather data and track the robot's progress, adopting a *trial-and-error* approach to placing blocks, particularly choosing between the left and right blocks.

In the *Private Awareness* condition, the pair began by using the same strategy of exploring the map visually and physically while closely observing the robot. Initially, C4-BVI was confused by the private audio cues, as indicated by his verbal responses (e.g., "hm?"). However, after adjusting, C4-BVI began repeating the information, either sharing it with his partner or acting quickly to make decisions. This led to a more competitive dynamic, as they both tried to be the first to place a block. C4-BVI would directly react to the private feedback, like wanting to remove a block after hearing the robot's feedback.

In the *Shared Awareness* condition communication and cooperation became more explicit. The pair thought out loud and took turns, with C4-S placing blocks based on instructions from C4-BVI. Both participants had a clear understanding of the robot's progress, with C4-BVI often giving instructions before the audio cue. Though C4-BVI placed fewer blocks in this condition, he played a significant role in guiding strategy and providing direction. Their anticipation of progress before the audio cues indicated a growing independence in identifying mistakes and problem-solving.

Throughout the conditions, G4 demonstrated strong collaborative problem-solving, frequently debugging mistakes together. However, despite their focus on the task, neither child fully grasped the concept of sequences, often leading to confusion about why the robot moved incorrectly. For instance, they struggled to understand why the robot moved forward without turning, causing it to miss the correct path when they had placed a left block followed by a forward block and the robot had a wall on its left side.

5.5 Group 5 - Silent Efficiency and Optimization

G5 established a strong collaborative dynamic from the first session, with both children taking turns placing blocks and solving challenges together with minimal verbal communication. Their efficient and focused approach across all conditions resulted in a notably fast performance, with fewer instructions from the researcher needed compared to other groups.

Their interactions reflected mutual respect and an awareness of each other's actions, even without much verbal exchange. This coordination was evident as they waited for their turn while the robot executed previous instructions, with minimal overlap, tension, or verbal communication. Even when both children had their hands in the programming area, they managed not to interfere with each other—one child removed previous blocks while the other placed new instructions. Although they did not express frustration toward each other, there were moments when they left their hands in the programming area during their turn, indicating a subtle competitive dynamic. Yet, their quick reactions and the speed of their decisions also implied a shared goal of speed in solving the task.

The pair initially adopted a step-by-step approach to programming the robot but quickly understood sequencing multiple instructions. C5-S's understanding became apparent when she suggested not removing a block needed for the next step, saying, "You can do that one; you do not need to remove it". Although there was occasional confusion, such as deciding whether the robot should turn left or right due to the activity's allocentric perspective, both children rapidly corrected their instructions through trial and error or by excluding incorrect options. At the end of each task, while they did not celebrate their success overtly, their expressions showed satisfaction. After completing the challenges, they used the dancing and speaking blocks—features they avoided during the problem-solving phase—demonstrating a sense of contentment and accomplishment as they collaborated to create fun sequences for the robot.

In the *No Awareness* condition, both children needed to rely heavily on observing the robot's movements to understand the outcomes of their instructions. They encountered difficulty when they did not realize in advance that the robot could not move forward, as there were no auditory cues to inform them of mistakes before they happened. For example, the group had to pay careful attention to where and how the robot was moving, as there was no audio input to guide them. This resulted in some errors, which took slightly longer to correct. However, despite these challenges, they remained fast and efficient, quickly figuring things out and maintaining their position as the fastest group overall.

In the *Private Awareness* condition, the group's dynamic regarding collaboration and communication style remained practically unchanged. A demonstration of awareness and collaboration was when C5-BVI would repeat the private feedback she received, sharing her awareness state with her partner, such as, "The robot spoke", or "It says it cannot (go that way)", but these instances were infrequent. This limited sharing of feedback may have been due to the minimal communication style that the group had already established, regardless of the condition. C5-S did not seem fully aware that C5-BVI was receiving verbal instructions, as C5-BVI only verbalized what she was hearing once, despite multiple errors where she could have offered more information. Despite this, the pair continued to work effectively, with C5-BVI using her awareness from the auditory cues to subtly inform her actions. C5-S appeared to rely on her visual perception and did not inquire much about C5-BVI's auditory feedback, maintaining their quiet collaboration.

In the *Shared Awareness* condition, there was a detectable improvement in their coordination and reaction times. When the robot said, "Oh, oh, I cannot go this way", both children instantly recognized the mistake and adjusted accordingly. C5-S in particular, responded quickly to the verbal feedback, looking at C5-BVI and changing the block almost instantly after realizing a mistake. In previous conditions, C5-S exhibited more confusion about what was wrong, while now, the auditory inputs provided clearness that allowed her to act more decisively. With the *Shared Awareness*, both children could immediately identify and rectify errors without moments of uncertainty, such as pressing two times the play button to be sure that the block was incorrect. Surprisingly, this feedback loop enhanced C5-S's speed and autonomy, where she increasingly took the lead, especially on the last map, where she dominated the task. The shared auditory cues appeared to empower her with the confidence to take more control while maintaining an efficient and collaborative dynamic. The auditory feedback plus her vision gave her an advantage that allowed for this shift in power dynamics.

5.6 Group 6 - Overhelping The Partner

The pair G6 exhibited an asymmetric approach to collaboration, with C6-S consistently dominating the task and guiding her partner's interactions across all conditions. At the start of each challenge, C6-S would take control by grabbing her partner's hand, physically exploring the map, and explaining the task. This behavior was consistent across conditions, where C6-S essentially provided C6-BVI with workspace awareness by guiding his hand to perceive the map and understand the robot's status.

In the *No Awareness* condition, C6-S exerted clear control over the task, often using her partner's blocks and instructing C6-BVI to press play after she had placed them. While focused on solving the challenge, C6-S kept her partner informed, though she did not consider his suggestions. C6-BVI followed her instructions, pressing play and verbally agreeing with her guidance, with most of his verbalization limited to "hm hm" in agreement. Here, C6-S adopted a *trial-and-error* approach, while C6-BVI played a more passive role, often expressing confusion and relying entirely on C6-S to understand the task.

In the *Shared Awareness* condition, despite C6-S's continued dominance, C6-BVI became more engaged, asking questions, making suggestions, and using the on-demand button. The auditory cues provided by the system helped improve C6-BVI's workspace awareness, although these cues had a different impact on C6-S. She found the feedback irritating, commenting, "Nobody asked you," and even attempting to take the *on-demand* block from her partner to avoid hearing the robot's voice again. C6-BVI found amusement in the robot's voice and laughed at it. Although C6-S continued to lead, both children used the audio cues to detect errors and debug collaboratively.

In the *Private Awareness* condition, C6-S again took the lead in problem-solving, directing C6-BVI to take specific actions. C6-BVI, however, displayed signs of disengagement, often talking about unrelated topics and asking about the task's progress, indicating that the private feedback alone wasn't sufficient to keep him fully involved. Initially confused by the private information, C6-BVI eventually began repeating the feedback to his partner, adopting a more cooperative role as the session progressed.

Interestingly, despite C6-BVI's initial excitement about owning a programmable robot at home, it was C6-S who consistently demonstrated problem-solving skills and algorithmic thinking. Over time, she moved from a step-by-step approach to constructing more complex sequences for the robot to execute, further solidifying her leadership role in their collaboration.

5.7 Cross-Case Analysis

Applying CT concepts Across all groups, it was evident that children applied CT concepts throughout the activity. In every group, either one or the pair effectively employed problem-solving strategies and completed all the mazes in each condition. A key aspect of their approach involved data collection, as the children would visually or physically explore the map at the beginning of each challenge to assess the full path the robot needed to take. In most groups, the auditory feedback in shared and private conditions supported their data collection, helping the children understand the progress and state of the robot.

Most groups initially adopted a step-by-step approach to programming the robot. However, some participants progressed to creating sequences, demonstrating a deeper grasp of algorithmic thinking (G3, G5, and C6-S). Notably, G5 not only was the fastest but was also the one making fewer mistakes and understanding the concepts of laterality and sequencing the blocks to optimize their effort.

All groups encountered instances when debugging was necessary to progress, where they needed to identify and correct errors in their programming. By observing the robot's behavior and using the feedback provided, the children would reflect on their mistakes, strategize the next steps, and reprogram the robot to follow the correct path. This iterative process of error detection and correction was a crucial part of their problem-solving approach.

Lack of workspace awareness The lack of workspace awareness throughout conditions created significant challenges for almost all groups, leading to confusion, slower progress, and reliance on *trial-and-error* strategies. C2-S, C1-S, C3-BVI, and C3-S became frustrated when the robot did not act as expected, repeatedly pressing the play block and looking to the researcher for help. C2-BVI, though more aware of the maze through tactile exploration, remained unaware of her partner's actions. G4 and G3 also struggled to track the robot's progress without auditory cues, depending heavily on visual and tactile exploration resulting in taking more time in the *No Awareness* condition over the other two. For G6 in the *No Awareness* condition, C6-S dominated the task with a *trial-and-error* approach, while C6-BVI played a passive role, frequently confused and relying on her partner for guidance.

Overall, the absence of workspace awareness hindered effective collaboration, leaving participants to guess progress and actions, and leading to slower task completion. At the same time, it also led to a reduced understanding, as they lacked real-time feedback on each other's actions and the robot's status in the maze. Across the *No Awareness* condition, there were higher expressions of confusion, leading to more errors, and repeated mistakes, as they were not able to anticipate or correct themselves or their partner's missteps in advance.

Private Information Impact In the *Private Awareness* condition, information was provided only to the child with BVI with the goal of balancing feedback. However, this often led to feelings of exclusion for the sighted partner. Children expressed curiosity over what their partner was listening to, or why they had an earphone and an extra block. Sometimes, this led to moments of confusion, frustration, and a sense of exclusion for the sighted child, who, contrary to the child with BVI, could not hear the instructions or understand why specific actions were taken.

For most cases, such as G1, G3, G5, and G6 the child with BVI remained almost silent, which created a more uneven dynamic. Although the child with BVI occasionally verbalized the auditory cues, they often did not share this information, which limited effective collaboration and reinforced power imbalances, stressing the challenges of one-sided information flow in maintaining equal participation and engagement. This asymmetry in information reduced effective teamwork and created a gap in shared understanding between partners.

For children with BVI, the private feedback also caused some confusion and imbalance in their participation. For instance, C2-BVI would grab blocks "late", after her partner had placed them, because she only acted after hearing that auditory feedback, causing delays in the collaboration. Both C4-BVI and C6-BVI, initially struggled to make sense of the private information, showing confusion and hesitation as they adjusted to relying on the audio cues.

Awareness-driven engagement In the *Shared Awareness* condition, both children received the same auditory feedback at the same time which supported their coordination and mutual understanding. There was an increase in the synchronization of their actions, where a common awareness of the task state reduced confusion and frustration, enabling both children to engage more fully and equitably in the activity.

However, while shared feedback fostered teamwork, it did not eliminate pre-existing power dynamics or dominant behaviors. In some cases, it even highlighted these imbalances. For example, in the case of G6, the sighted child (C6-S) gained a stronger sense of control over the task. With dual input—both visual and auditory—C6-S was able to respond more quickly, taking the lead in decision-making and task execution. This increased confidence reinforced a power dynamic that limited the participation of C6-BVI, reducing opportunities for more equal collaboration.

The shared feedback also enhanced error correction and learning. Both children, hearing the cues simultaneously, were able to identify and resolve mistakes quickly leading to joint problem-solving. This contrasted with situations where information was limited or one-sided, resulting in repeated errors and slower progress.

6 Discussion

In this paper, we deepen our understanding of how workspace awareness shapes collaboration in a programming task for mixed-visual ability children. Such understanding is essential for addressing the current gap in designing environments that promote positive and balanced experiences for mixed-visual ability groups of children. Prior research has shown that mixed-visual ability collaborative settings can enhance social and academic development, and foster inclusive behaviors [43, 55], and workspace awareness significantly impacts each participant's sense of contribution and participation. This, in turn, is vital for achieving shared intentionality among group members [54].

To answer our research question, *How does workspace awareness shape group dynamics in a collaborative programming task among children with and without visual impairments?* we highlight the children's experiences and the different impact of the three distinct awareness conditions on task performance and collaboration dynamics, regarding their participation and engagement. We conclude with design considerations for future collaborative inclusive tangible programming environments.

6.1 Familiarity Influence in Collaborative Dynamics

The familiarity between pairs provides a base for shaping their collaboration dynamics. Children's personalities and their empathy toward their partners affected the impact of the provided workspace awareness. For instance, G4 and G5, who had a pre-existing relationship and frequently played together, demonstrated effective collaboration, frequent communication, and shared enjoyment in all conditions. In G4, the children displayed increased cooperation and cordial behavior, patiently waiting for their partner to assess the situation before taking their turn. In the *Private* and *Shared Awareness* conditions their communication and cooperation was explicit, leading to C4-BVI becoming more communicative during problem-solving moments. Similarly, in G5, where the children had an established minimal communication style, the shared awareness condition enhanced their speed and flow, improving their overall efficiency.

Conversely, in G1 and G2, the children only knew each other from class and did not typically play together, and their communication was less effective, leading to frustration and disappointment. **In the *Private* and *Shared Awareness* conditions, the children with BVI made more efforts to communicate and participate.**

In G1, C1-BVI was more engaged than in the *No Awareness* condition but more interested in exploring the blocks with increased auditory feedback (speaking and dancing). In G2, C2-BVI initially experienced a lack of awareness and cooperation, largely due to her partner's individualistic approach limiting collaborative interaction. However, in the conditions that provided auditory workspace awareness, C2-BVI increased her attempts at participation and communication, becoming more engaged in the task. This change highlights the positive impact of enhanced workspace awareness in empowering children to contribute. A similar dynamic occurred in G3 during the *Shared Awareness* condition, where C2-BVI was taking over the task and C2-S shifted her behavior to react quickly to the auditory feedback and attempt to cooperate with her partner.

In contrast with the other groups, G6 had a pre-existing relationship where the pair frequently played together and there was a dominant behavior from the sighted child in all conditions, which became more pronounced. This dynamic mirrored what happened in G3 during the *Private Awareness* condition, where C3-BVI dominance hindered his partner's participation.

The observed behaviors align with the Interdependence Model of Disability [19], emphasizing that effective collaboration between sighted children and children with BVI depends on balanced participation, where both contribute equally and benefit from shared support. For instance, G4 and G5 demonstrate how their interactions reflect the model's principles of reciprocity, with both children benefiting from cooperative problem-solving. This suggests that the design of such technologies should account for balanced workspace awareness to promote the kind of interdependence the model advocates, reducing power imbalances and fostering mutual participation in mixed-visual ability collaborations.

6.2 Shaping Group Dynamics

All groups were able to complete the challenges and applied CT concepts as expected from previous work in inclusive tangible programming environments [31, 48, 50]. However, several key patterns emerge from the observed behaviors across different conditions. Notably, these patterns underscore the significant impact of workspace awareness on both the efficiency and effectiveness of group interactions and task performance.

In the *No Awareness* condition groups faced notable challenges. The lack of shared understanding of each other's actions led groups to take longer to solve the challenge, with less effective communication and more time to perceive and correct mistakes (G1, G2, G3, G4). Both children experienced reduced awareness of the other's actions, with children asking their partner what they were doing or what block they placed. For example, C2-BVI was even surprised by the robot's movement because she didn't realize her partner had instructed it to move. This disconnect in awareness not only hindered immediate task execution but also resulted in increased reliance on external guidance, such as looking to the researcher for help (G1, G2, G4).

Without auditory cues, these issues were aggravated by forcing children to rely solely on visual and/or physical exploration of the workspace. This often led to a *trial-and-error* approach, where children repeatedly pressed the play block without modifying their code, expecting different outcomes (G2, G4). Such behaviors reflect a deeper issue: **without clear cues or feedback, children struggled to recognize and correct their mistakes promptly, leading to repetitive errors and inefficient problem-solving.**

Moreover, the lack of workspace awareness resulted in disengagement among group members. When faced with unbalanced participation, children often diverted their attention from the task (G1, G3, G6). This disengagement underscores the importance of maintaining a shared understanding of the workspace to foster active participation and collaboration, avoiding creating an unbalanced experience [48].

In the *Private* and *Shared Awareness* conditions, we observed that the auditory feedback was relevant for children to feel included and empowered to participate, particularly for children with BVI. In the *Private Awareness* condition, the auditory feedback was instrumental for children with BVI as they heavily relied on the cues to stay aware of the task and their partner's actions. In contrast, the *Shared Awareness* condition demonstrated the potential of auditory cues to foster a shared understanding of the task and each other's actions, significantly improving coordination and mutual awareness between partners.

In the *Private Awareness* condition, the auditory cues served more of a supporting role. For example, C1-BVI was focused on listening to the cues but did not make use of them to enhance collaboration or guide the task. However, C4-BVI showed a gradual improvement, adjusting over time as she received auditory feedback to make quicker decisions. This suggests that while feedback in the private condition can improve workspace awareness, participants may need time to adjust before the feedback influences collaborative dynamics positively.

Providing simultaneous feedback to both participants promoted more synchronized actions and collaborative behaviours. Therefore, **in the *Shared Awareness* condition, the dynamics of collaboration were improved compared to other conditions, leading to more effective communication and enhanced performance overall.** The integration of auditory feedback enabled both children to hear each other's actions and intentions, fostering a more synchronized and engaged collaboration. This shared awareness was evident in various moments of the task, such as when C1-BVI and C1-S experienced a shared sense of achievement and problem-solving. Or, for instance, when children anticipated the movements and demonstrated keen workspace awareness by interpreting audio cues and proactively offering guidance like, "No, it has a wall", and "Now you have to go right", improving their ability to anticipate and respond to the robot's actions.

This condition facilitated clearer communication and more explicit cooperation, engaging in collaborative problem-solving and debugging. The shared verbal feedback also allowed the children to recognize and correct mistakes collectively, as illustrated by C1-BVI's reaction to a mistake, which was met with a smile shared with her partner. Overall, the *Shared Awareness* condition not only improved the groups' ability to identify and rectify errors but also enhanced their coordination and reaction times, demonstrating the critical role of workspace awareness in fostering effective and engaged collaboration.

The significance of enhanced workspace awareness was highlighted by instances where the absence of audio cues led to an imbalanced experience and frustration among the children. For instance, C3-S expressed frustration by saying, ´´This (block) does not speak. These blocks don't speak", emphasizing the challenge of coordinating actions. The lack of balanced information hindered effective collaboration and reinforced power imbalances. However, our observations suggest that while auditory support is beneficial, it alone is insufficient to ensure balanced participation. More targeted strategies are needed to promote effective teamwork and balance the shared experience.

Our findings show that varying levels of awareness directly influence group dynamics and collaborative behaviors, making awareness a flexible tool that can be manipulated to serve specific goals. While shared awareness generally improves coordination and collaboration, there are settings where private or asymmetrical awareness might be more effective. For example, tasks requiring shifts in control or responsibility, as seen in mixed-ability gaming [14, 38].

When designing with awareness the cognitive load for the participant must also be considered. Excessive or poorly timed information can overwhelm or frustate participants [7]. One potential solution is on-demand awareness, allowing participants to access information only when needed, although this approach was underutilized in our study. Alternatively, dynamic adjustments based on real-time task performance or an external intervention, like a teacher, could ensure awareness is provided precisely when it is most impactful. These findings emphasize that awareness should be treated as an adaptable feature. Designers should consider how and when to integrate awareness to support collaboration, maintain task efficiency, and minimize cognitive strain.

6.3 Design Considerations

From both the literature review and the findings presented in this paper, we understand there are no universal design guidelines to apply and support collaboration in every context. However, our findings enable us to propose design considerations for inclusive collaborative technology. One key insight is the importance of incorporating adjustable system features, such as auditory feedback frequency or player-specific cues. For example, we observed that auditory feedback in private and shared conditions significantly influenced children's sense of inclusion, empowering them to participate and fostering efforts to communicate more effectively. Moreover, the system can also play a compensatory role by moderating interactions to limit dominating actions, providing targeted support to balance participation, and fostering a more equitable environment that enhances collaboration.

Calibrating Dynamics - In our study, we observed that previous relationships shaped the collaboration and communication style of each dyad. Even under the different conditions, their familiarity had a great influence on their teamwork. Cohen[8] emphasizes the importance of preparing students for groupwork rather than assuming they have the preparation to collaborate with their peers or without teachers' supervision. Integrating *icebreakers* or *skillbuilders* activities within the system could help children familiarize themselves with both the system and their partner, fostering a sense of comfort and collaboration. For example, smaller preliminary activities could be designed to help children develop an awareness of their partner's needs and practice specific cooperative behaviors. Children can build confidence in communication and participation by engaging in a brief collaborative task before tackling programming challenges, setting the stage for a more successful collaborative experience.

Robot and Tangible Blocks as mediator - During the sessions, we could observe moments of interaction where one child would dominate the task and even overpower their partner. Using the technology to mediate and guide interactions can be done through the robot using approaches such as verbal directions and physically approaching the child to indicate whose turn it is to put the blocks, identify who is the least participative, and encourage them to intervene. This approach is similar to previous work with robots in mixed-ability groups to balance participation and turn-taking in conversational contexts [33].

Another example is based on Hoffman et al.'s work [20] with the Kip1 robot demonstrating how robots can mediate interactions by using gaze cues to balance participation and reduce tensions, which could be an interesting approach enhanced with audio or touch to mitigate the imbalanced dynamics for mixed-visual ability groups, as observed in the *No Awareness* condition in G1 and G3 in all conditions. By putting the robot as a mediator, previous studies showed an enhanced human interaction by looking and leaning at a person to establish which turn it is, creating a sense of attentiveness without direct mediation, encouraging balanced engagement [32, 47], and help overcome intergroup biases and foster inclusion [13].

Incorporating mediation characteristics directly into the blocks could allow the programming system to guide and encourage balanced participation, making it a more integrated and seamless experience for children. This strategy could help children understand turn-taking and collaboration dynamics without requiring a separate mediating device, like the robot, potentially enhancing engagement and reducing reliance on external cues. Neto et al. showed that improved haptic feedback tangibles could enhance inclusive, collaborative learning for children with visual impairments by providing haptic feedback [35]. Also, Zhang showed that a tabletop game board with collaborative enforced rules encourages player collaboration, improving empathy and engagement and reducing negative feelings.[60]

Interdependent Responsibilities - We did not explicitly consider asymmetric or interdependent roles based on ability or action in our study. However, our *Private Awareness* condition created a capability-based split, enabling interdependency between the two children. The sighted children had access to visual information, while the children with BVI received audio information. This distribution of capabilities led to children assuming interdependent responsibilities, enabling more effective collaboration. However, as seen in previous research, introducing role asymmetry fosters implicit cooperation in mixed-ability settings, with role differentiation and storytelling effectively bridging gaps in skills or knowledge by leveraging each child's strengths [14, 43, 50]. Rather than a uniform approach where the system compensates for skill disparities, the system could play a more active role in enhancing accessibility by highlighting each child's unique strengths. For example, incorporating a tactile approach that influences programming mechanics and leveraging private information to create interdependence between the group. This could even be enhanced by storytelling, where each child plays a distinct role and the narrative can prompt turns for each role, ensuring that both participants rely on each other to progress.

7 Limitations

The sample size and diversity of participants in this study may limit the generalizability of the findings. The study included a relatively small number of pairs (6), all from the same country, which may not fully represent the range of interactions and dynamics that could occur in broader settings. Additionally, the specific design of the programming tasks and the technology, may not capture all the complexities of real-world collaborative activities. In our study, we did not consider or assess gender dynamics within the group collaboration. However, research shows gender socialization in early childhood can already influence children's behaviours in group settings. By age 10, children often internalize gender norms, shaping tendencies like cooperation, dominance, and accommodation [17, 26]. Future work could explore how gender dynamics affect collaboration in mixed-ability pairings by analyzing role assumptions, levels of engagement, and participation across different gender combinations. Considering this factor could offer deeper insights into the social interactions observed and guide future efforts to promote a more inclusive and balanced collaboration.

This study did not explore the long-term effects of frequently using the tool on the collaboration dynamic of the group, influencing their participation and engagement over their previous relationships.

8 Conclusion

In this paper, we explored the role of workspace awareness in collaborative programming tasks involving children with mixed visual abilities. By exploring various levels of auditory feedback on workspace awareness—no awareness, private awareness, and shared awareness—through auditory feedback in a tangible coding environment, we gained insights into how these factors influence children's experiences and perceived participation.

Our findings reveal that workspace awareness significantly impacts engagement and the promotion of active participation in collaborative tasks. We also reflected on the impact that children's established power dynamics or their empathy towards each other's strengths and limitations play in shaping the base for group interactions. These insights underscore the importance of designing collaborative programming systems that accommodate diverse abilities and promote equitable participation. Integrating appropriate workspace awareness features in accessible programming environments can better support children with mixed visual abilities, facilitating improved collaboration and enriching learning experiences. Our study emphasizes the need to design collaborative programming environments addressing the technological aspects and the relational dynamics between participants. By considering these factors, future systems can better accommodate diverse needs and promote a more inclusive and effective collaborative experience.

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