Exploring Collaboration in Programming Activities with Children with Visual Impairments: a 10-Session Study in a School Setting

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Fig. 1. Children engaging in activities. On the left, during session 3 with a shared goal and asymmetric information (*Captain* role). On the right, during the activity with map sharing and rewards in session 10.

Introductory coding environments have been used in early education to promote computational thinking, supporting the development of cognitive, critical, and social skills. Many environments focus on individual use, which has limited benefits compared to collaborative learning. In this paper, we present the results of a 10-session study at a local primary school engaging eleven children with visual impairments and three inclusive education teachers in collaborative programming activities. Based on participants' behavior, reactions, and feedback, we contribute an improved understanding of collaborative design in educational settings, focusing on the impact of Goals, Workspace, Interdependence, and Shared Awareness. Our main findings outline how collaboration dynamics can be shaped by asymmetric tasks, workspace proximity, and group awareness. We further discuss factors that led to a lack of investment in the shared goal and instances of unbalanced collaboration, reflecting on challenges and opportunities for designing collaborative inclusive coding kits.

CCS Concepts: • **Human-centered computing → Empirical studies in accessibility**; Computer supported cooperative work; *Field studies.*

Additional Key Words and Phrases: Visually impaired, Mixed-visual ability, Children, Computational thinking, Collaboration, Tangible, Robot, Accessible

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1 Introduction

Introducing children to computational thinking (CT) at an early age promotes computational literacy and fosters the development of critical, cognitive, and social skills [49]. Consequently, in the last two decades, there has been a growing effort to include introductory coding environments, such as Scratch [40], in educational settings [16]. While these mainstream coding kits have been shown to reduce cognitive load and enhance creativity and learning [4, 46], they present barriers for children with visual impairments due to their heavy reliance on visual elements [16, 37]. A recent shift towards integrating multimodal elements into coding kits holds significant potential for creating inclusive learning environments that cater to diverse abilities [8, 25].

While many coding kits are focused on individual use [2, 26], there has been a growing interest in designing collaborative learning environments to encourage students to work together while promoting inclusive activities [25, 31, 47]. Indeed, collaboration as an educative approach benefits children's learning process by fostering critical thinking, social and communication skills, and improving overall academic achievements while promoting inclusive behaviors [12, 20]. Recent work has leveraged tangibles and robots to demonstrate the potential of accessible coding environments in facilitating communication and successful collaboration between children with visual impairments and their peers [28, 42] or their families [43].

We recognize a gap in the literature on exploring different factors to enhance the collaborative behaviors of children with visual impairments in coding environments. To address this, we focus our investigation on the following research questions: **RQ1:** How should we support collaboration in non-visual computational thinking activities?; **RQ2:** What factors positively influence collaboration in a school setting? To answer these questions, we engaged in design-action-reflection cycles along a 10-session program with children and their educators at a local public school. With the aim of introducing children to CT in a collaborative environment, the teams had to cooperate in navigating a robot on a map. Throughout these sessions we explored multiple design approaches to elicit collaboration between children, varying four core design concepts: Goals, Workspace, Interdependence, and Shared Awareness.

Our results underline how asymmetric design with interdependent roles successfully promoted different collaboration dynamics, which were shaped by the tasks each role implied and workspace proximity. Despite the elicited collaboration, we found a lack of investment in the shared objectives and achievements, with children mostly focused on their individual tasks. A wide range of abilities and needs within the groups also led to instances of unbalanced collaboration and awareness, where more autonomous children got frustrated for having to wait, sometimes ignoring and/or assuming others' responsibilities. We also describe how specific elements attracted children's interest (in particular, novelty and storytelling) and what aspects interfered with learning, autonomy, and ease of use (e.g., doubts regarding the robot movement).

In this paper, we contribute (1) an empirical account of the design, prototyping, and implementation of collaborative multimodal coding environments for children with visual impairments; (2) a reflection on the impact of the elements and factors we employed on promoting participation and collaboration during coding activities; and (3) a reflection on the challenges and opportunities for the design of collaborative coding kits for children with visual impairments. The findings of this research contribute to a deeper understanding of the design of inclusive and empowering educational experiences for children with visual impairments.

2 Related Work

In this section, we emphasize the importance of introducing CT in education, highlighting its potential to enhance logical reasoning and foster the development of social skills and collaboration among children. We discuss the relevance of multimodal technology in supporting CT learning for children with visual impairments and then present prior work on supporting collaboration among children with mixed visual abilities.

2.1 Computational Thinking

Seymour Papert initially coined the term Computational Thinking, envisioning the integration of CT into everyday life [34]. Papert believed interacting with computers could transform children's thinking and learning by developing critical problem-solving skills and logical and analytical thinking. Later, Wing, in her seminal paper [49], defined and brought to light the relevance of CT in education, advocating for integrating CT into all educational levels to equip students for the challenges of the modern world. Although interpretations of CT have varied, a common thread is its description as the cognitive processes necessary to identify problems and develop solutions that can be executed effectively [50]. CT's relevance extends beyond the domain of computer science, emerging as a skill with diverse applications that fosters critical and logical thinking, problem-solving, creativity, and social skills [4, 15, 49].

Central to CT activities is the learning of coding, which includes mathematical, spatial, verbal, and social reasoning [46]. However, a significant challenge in fostering inclusive CT learning environments is the scarcity of coding kits and tools that are both accessible and engaging [19, 29, 37]. Educators often face challenges and adapt their teaching methods to address the accessibility limitations of current coding tools and kits [29].

2.2 Inclusive and Multimodal Robotics

Research has begun to address the accessibility gap by designing coding kits with the needs of children with visual impairments in mind [16, 30]. Children with visual impairments require educational strategies and technologies tailored to their unique needs. While schools are committed to supporting these students, they often face significant challenges, including inadequate training, insufficient staff and materials, and limited access to the necessary technology [14, 38]. The needs of students with visual impairments can be varied, depending on their visual acuity, comorbidities, and sensory sensitivity, among other factors. For instance, students with low vision benefit from magnification tools, enhanced lighting, and high-contrast materials. On the other hand, blind students rely exclusively on tactile and auditory tools for learning, such as Braille and screen readers. CT and digital literacy are particularly challenging as the concepts are mostly visual or hard to conceptualize without concrete visual/physical representations. Schools struggle to find innovative ways to make these subjects accessible and often use tactile graphics, 3D models, and auditory descriptions to convey complex concepts [22].

Multimodal coding kits that engage various sensory modalities enrich conceptual knowledge, aiding higher-level cognitive functions, and are especially relevant for children with visual impairments [18, 39]. Children can gather multiple sensory information crucial to understanding spatial relationships, size, shape, and surroundings [18, 41], as well as causality between their actions and the environment.

A common and engaging approach to teaching coding is through robotics [4]. Robots have captivating physical attributes and have emerged as powerful multimodal tools to facilitate CT learning and inclusive behaviors among children [16, 24, 37, 47]. Beyond being mere programming outputs, robots have been deployed to aid in learning basic skills like letters and shapes, or to boost inclusive play in schools [1, 31, 36]. Blocks4All [26], for example, is an accessible multimodal robotic kit making use of a screen reader to access the block-based platform to program a physical robot on the floor. However, using the screen reader and coding with virtual blocks can be highly cognitively demanding to children with visual impairments.

Alternatives to traditional tools have shifted from keyboard-based interfaces supported by accessibility services, such as screen readers, to more tangible and multimodal solutions. Recent studies [28, 37, 43] have explored the use of multimodal robotics, showing their potential in developing children's spatial abilities, orientation, and mobility skills. These approaches allow children to use tangible blocks to guide the robot from one point to another while avoiding obstacles, integrating spatial tasks with both tangible and auditory output [36, 37, 43]. These studies indicate that multimodal robotics have the potential to foster both learning and participation for children with visual impairments and their sighted peers [36, 37, 42]. Blending multisensory elements, such as the auditory feedback from the characters and the robot, with tangible interaction enabled children to create a dynamic, inclusive learning experience that could foster cognitive, social, and motor skill development [36].

2.3 Collaboration in Learning Environments

Collaboration takes a central stage in educational settings. This approach to learning, known as collaborative learning, has multiple benefits. It fosters critical thinking while cultivating social interaction and communication skills, contributing to improved overall classroom performance [12, 20]. Additionally, collaboration is crucial in embracing diversity among individuals with varied abilities.

In this context, technology could also promote inclusion and collaboration among children with mixed visual abilities [14, 24, 32, 36]. A key factor for successful collaboration is maintaining awareness of the environment and the current state of others [10, 28]. However, this can be notably complex in mixed visual ability scenarios [10], especially in activities demanding comprehension of others' actions and conscious awareness of the surrounding environment. Tangible objects represent an engaging and interactive way for children to be aware of the environment, enabling individuals to access tactile information at any point during the activities and encouraging them to have exploratory behaviors, as well as to share and communicate with others [11, 21, 35]. Through tangible representations, children can exchange skills, observe peer actions, and keep track of play status (leading to awareness), with a common entry and access points (leading to shareability), all of which are vital for collaboration [47, 48]. Haptic virtual environments with tactile feedback can also enhance teamwork among children with mixed visual abilities [27].

Morisson et al. [28] explored multisensory elements (touch and audio) for children to learn to code collaboratively. They created Torino, a collaborative, accessible, and tangible programming tool designed for children aged 7-11 [47]. Children connected physical instruction beads to create auditory output, such as music or stories. Their findings highlighted tactile and audio feedback as crucial access points for mutual awareness. They demonstrated that a multimodal and inclusive environment leveraging mutual awareness could facilitate meaningful social interactions and learning among children with mixed visual abilities.

Two research studies emphasize the delicate balance between providing appropriate levels of awareness, its impact on communication and collaboration, as well as the influence of design choices on these dynamics. Rocha et al. [42] developed a tangible robotic kit, inspired by the game Sokoban, to investigate CT collaboration with asymmetric roles among children with mixed visual abilities in both co-located and remote settings. The study observed an increase in communication in remote collaboration scenarios, attributed to the participants' limited awareness of their partner's actions and workspace. In another study by Chibaudel et al. [7], participants performed a collaborative treasure hunt task using a robot that could be either passive or active. In the active mode, the robot provided information about the peer's location, which enhanced the overall efficiency of the treasure-hunting task. However, pairs tended to collaborate less as the task shifted more toward guidance. These findings [7, 42] collectively reveal that there is a need to balance awareness levels, as giving too much or too little can impact the activity or the collaboration and communication within the group.

Using narratives can play a key role in enhancing awareness and engagement for children with visual impairments [36, 42, 47]. Furthermore, they can provide meaningful experiences that foster collaboration in solving challenges. Role-play activities further promote social play and collaboration by assigning different roles or social practices to children [13, 44]. For example, in online gaming, interdependent asymmetric roles leveraging different sensory feedback reinforced control and appreciation of each participant's contribution, highlighting the importance of communication for game progression [3, 13].

Besides increasing accessibility and inclusion, these collaborative methods are engaging and have the potential to enrich learning experiences by promoting collaboration, critical thinking, and group discourse [8]. However, there is still a gap in understanding the factors that impact and facilitate collaboration in CT learning environments for children with mixed visual abilities.

3 User Study

In collaboration with a local public school, we ran a 10-session study to engage children with visual impairments and inclusive education teachers in collaborative CT activities. We designed the sessions following an iterative process where we reflected and iterated over the activities (i.e. introducing new elements and rules from session to session) based on feedback given by teachers and children, and our observations (Fig. 2). We aimed to understand how the introduced elements affected children's collaboration and engagement, focusing on their behaviors and reactions during the session. We maintained meetings with the inclusive education teachers (IET) to better understand the challenges and opportunities they identified during the study.

The initial six sessions were held in 2022, and the last four sessions were conducted ten months later in 2023. These were scheduled according to the mutual availability of the children, researchers, and teachers. At the end of the ten sessions, we interviewed children individually to gather insights into their preferences and motivations. We also interviewed teachers to gain a more comprehensive understanding of the factors that influenced and impacted the activities.

The study was approved by the pedagogical board responsible for supervising, coordinating, and guiding quality pedagogical and educational activities at the local school where the activities took place. Parents or tutors signed consent forms, while children verbally assented to participate and were informed they could withdraw at any time during the study. We implemented recommended accessibility design guidelines for the system and activities, adhering to our university's ethical code and leveraging over ten years of researchers' experience working with children, including more than five years with children who have visual impairments, to ensure a supportive and inclusive environment. Additionally, at least two IETs were present to assist the children in all sessions.

3.1 Participants

A total of eleven children (C1-C11) between the ages of 7 and 16 (M=10, SD=2.8), all attending the 1st-4th grade considering the national curriculum, participated in our sessions [Table 1]. Seven of these also participated in the final structured interview. Four children were blind, and the remaining had low vision ranging from low (one child) to medium (three) to high (three) visual impairment.

ID	Gender	Age	Visual Ability	Coding Experience	Sessions	Interview
C1	M	11	Blind	Yes	S1-S4, S6-S10	Yes
C2	M	8	HVI	Yes	S1-S6	No
C3	F	10	MVI	Yes	S1-S4, S6-S10	Yes
C4	F	7	MVI	Yes	S1-S6	No
C5	M	10	Blind	Yes	S1-S4, S8, S10	Yes
C6	M	16	Blind	Yes	S1-S4, S6-S10	Yes
C7	M	14	HVI	No	S1-S4, S6-S10	Yes
C8	M	9	MVI	No	S1-S4, S8, S10	Yes
C9	F	11	HVI	No	S9-S10	Yes
C10	F	7	LVI	No	S7	No
C11	M	8	Blind	No	S8-S10	Yes

Table 1. Information about the children who participated, including gender, age, visual ability (blind, high, medium, and low visual impairment), previous coding/robotic experience, in which sessions the children participated, and if they were interviewed.

Six children had previous robotic or coding experience. Three IETs also participated in the activities and a final group interview (T1-T3).

3.2 Sessions Design and Planning

The first session served to introduce a set of robotic kits and allow children to explore them freely, namely: the Sony toio kit [45], the Ozobot Evo and its coding pens [33], and prototypes based on the ACCembly [43], and the TACTOPI [36] works. We aimed to observe children interacting with all the elements to identify barriers to accessibility and opportunities in using each one.

We followed an iterative research process to plan and refine the following sessions, consisting of 1) gathering knowledge/feedback from the teachers, children, and researchers involved, 2) preparing the activities, and 3) running the session at the school with teachers' involvement. We made adjustments from session to session[1], adding and removing components, as well as adjusting the rules of the activity according to the feedback and specific aspects we wanted to explore. These changes are encapsulated under four design concepts: 1) Goals, 2) Workspace, 3) Interdependence, and 4) Shared Awareness. Below, we detail the physical components used during the sessions and describe the changes and the reasoning behind them, organized by the aforementioned four concepts. The outline of sessions is summarized in Figure 3.

3.3 Physical Components

Every session included a set of physical components namely the coding blocks, robots, maps, and devices to play audio (either headphones or a speaker).

3.3.1 Coding Blocks. In each session, children used the tangible coding blocks available for programming the robot's behavior: moving (forward, backward, left, or right), dancing (i.e. the robot spins while music is played), and speaking (i.e. a greeting is played). Children could build a sequence with these blocks by positioning them horizontally from top to bottom. They had to use the play block (positioning it at the bottom of the sequence) to execute the sequence. To repeat an action twice, children could use the loop block. The coding blocks consist of LEGO bricks with 3D

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[1] We paired some sessions, opting to repeat the same activity with the same elements for two consecutive sessions when we needed a more complete understanding of their impact (e.g., in S4 we conducted the activity with only two children and we repeated it in S5 with more children).

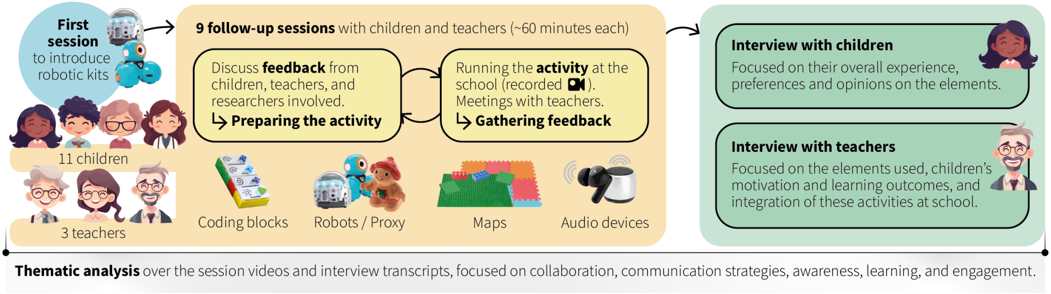


Fig. 2. Outline of the design-action-reflection cycles during the 10 sessions with children and teachers' participation.

patterned reliefs enabling children to identify the block's function (e.g., the movement blocks have blue embossed arrows). The blocks are inspired by the design of previous work [6].

In S1-S4, the coding blocks had Topcodes and were recognized by an app on a mobile phone that transmitted the sequence of actions for the robot to execute. In the remaining sessions, due to the short timeframe to prototype between sessions, we chose to rely on a Wizard of Oz approach, where the researchers controlled the robots through the companion app to act according to the sequence built by children with the physical blocks.

3.3.2 Robots & Maps. In S2-S4, we used the Dash robot [51] as the lead character in the proposed challenges along with a multicolored sponge map on the floor. This setup enabled children to explore the map by crawling on top of it and following the movements of the robot. In S7-S10, we used the Ozobot navigating on top of a smaller map, made of LEGO pieces—LEGO bricks as walls and landmarks (starting house) along with 3D-printed caps to create the path.

In S5-S6, we did not use any robots and instead, we followed an unplugged approach, where children had to move a LEGO figure in the LEGO map, according to the instructions given (as a proxy). With the unplugged robot, we intended to encourage children to work on their perspective-taking and orientation skills while understanding the execution, state, and progress awareness of the program. The unplugged robot was also used in S9 and S10, along with the Ozobot (sharing the same map). We used animal models and toys (e.g., LEGO panda) to mark the objectives on the maps.

3.4 Goals

The goal proposed for all sessions was similar, with children having to program the robot to reach a certain location or a set of locations. This goal was presented to children with an associated background story in every session (e.g., "the robot wants to meet its friends at a party in the forest"). As they progressed in the activity, the story would also develop (e.g., by speaking to the Penguin, children would find that the Seal held the key"). To progress, they had to program the robot's movement and use action blocks (dance, speak) to overcome special obstacles (e.g., dancing made the magical bush disappear). In S2, this goal was individual with children taking turns programming the robot and potentially helping each other. From S3 onwards, the group had a shared goal and children had to collaborate to succeed.

3.4.1 Mapmaker. In most sessions, the goal of the activity (and its associated background story) was pre-determined by the researchers. In S7-S8, the goal was determined by the child playing as the *Mapmaker*, who had to build a map layout, set up the challenge (e.g., reaching the giraffe), and optionally create a story to support the challenge.

3.4.2 Open-ended Goal with Rewards. In S10, we introduced a “sandbox" map with various landmarks along the path representing chores children could complete by programming the robot to reach these locations. When navigating the map, children could choose between different activities to perform along the path to receive stars (e.g., reaching the building in flames to extinguish the fire). They could then use the stars at checkpoints on the map to exchange them for customization items for their robots (e.g., hats, tails) and sound effects (e.g., horse trot when the robot moves).

3.5 Interdependence

From S3 onwards, we designed the activities to create degrees of interdependence between children to promote collaboration. To achieve that, we leveraged asymmetric design to have children play different roles that, in turn, had to contribute to the shared goal at hand.

3.5.1 Asymmetric Responsibilities. Across the sessions, we created five different roles with specific responsibilities: the *Pilot*, the *Engineer*, the *Explorer*, the *Captain*, and the *Mapmaker*. To explore different dynamics and degrees of interdependence, we made different groupings with these roles in the sessions (e.g., in S2, groups were composed of one *Pilot*, one *Engineer*, one Explorer, and one *Captain*). At the start of each session, we assigned children to the roles and made them switch during the activity, aiming to have children try all the roles.

The *Pilot* was responsible for using the programming blocks to program the movement of the robot; the *Engineer* was responsible for the *action* blocks (dance and speak) to program the robot to execute those actions and to initiate the execution of the sequence by using the play block. In S3 and S4, the *Pilot* and the *Engineer* had to work together to create sequences of movement and actions to reach the objectives. From S4 onward, the *Engineer* role ceased to exist and the *Pilot* assumed control of all coding blocks and was fully responsible for programming the robot.

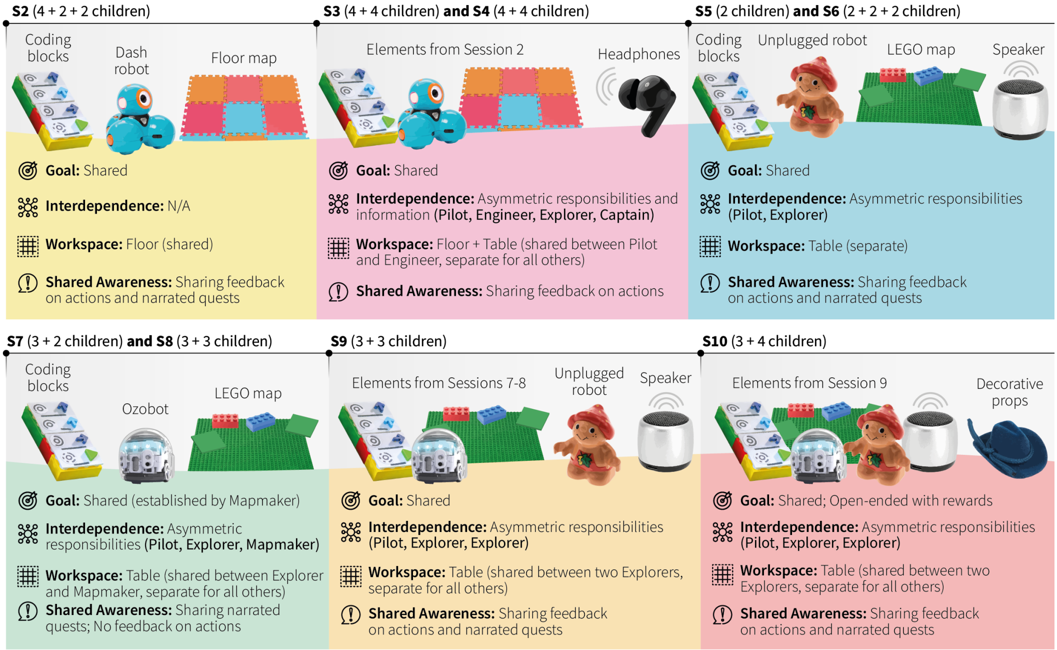
The *Explorer* was responsible for the map, giving feedback on the robot’s actions, figuring out what it had to do (in terms of movement and actions) to reach the objectives, and communicating these instructions to the *Pilot/Engineer*. The *Mapmaker* was responsible for setting up the goal of the activity, as described before.

3.5.2 Asymmetric Information. In S3 and S4, groups had a child playing the *Captain* role. This role had access to exclusive information that was conveyed auditorily through earphones. This information consisted of the story fragments that introduced the goal(s) of the activity. As such, the *Captain* was responsible for transmitting this information to the other children.

3.6 Workspace

All children worked either on the floor or sitting at a table. In S2, all children worked on the floor, around the sponge map. In S3 and S4, only the Explorer worked on the floor with the sponge map, while the other children sat at the table. In these sessions, the *Pilot* and the *Engineer* would sit with their backs turned to the map in an attempt to promote communication with the *Explorer*. In the remaining sessions, children worked while sitting at a table.

3.6.1 Separate and Shared Workspace. Typically, children had their workspace containing the physical components they were responsible for, according to the role they were playing (e.g., the Explorer had access to the map and its elements). However, in some sessions, children had to share a workspace: in S2, the workspace was fully shared (the whole group had access to the floor map and the baseplate to build the sequence); in S3 and S4, the *Pilot* and the *Engineer* shared the baseplate to build the sequence (while retaining control over specific coding blocks); in S7 and S8, access to



S2 (4 + 2 + 2 children)

Goal: Shared

Interdependence: N/A

Workspace: Floor (shared)

Shared Awareness: Sharing feedback on actions and narrated quests

S3 (4 + 4 children) **and S4** (4 + 4 children)

Goal: Shared

Interdependence: Asymmetric responsibilities and information **(Pilot, Engineer, Explorer, Captain)**

Workspace: Floor + Table (shared between Pilot and Engineer, separate for all others)

Shared Awareness: Sharing feedback on actions

S5 (2 children) **and S6** (2 + 2 + 2 children)

Goal: Shared

Interdependence: Asymmetric responsibilities **(Pilot, Explorer)**

Workspace: Table (separate)

Shared Awareness: Sharing feedback on actions and narrated quests

S7 (3 + 2 children) **and S8** (3 + 3 children)

Goal: Shared (established by Mapmaker)

Interdependence: Asymmetric responsibilities **(Pilot, Explorer, Mapmaker)**

Workspace: Table (shared between Explorer and Mapmaker, separate for all others)

Shared Awareness: Sharing narrated quests; No feedback on actions

S9 (3 + 3 children)

Goal: Shared

Interdependence: Asymmetric responsibilities **(Pilot, Explorer, Explorer)**

Workspace: Table (shared between two Explorers, separate for all others)

Shared Awareness: Sharing feedback on actions and narrated quests

S10 (3 + 4 children)

Goal: Shared; Open-ended with rewards

Interdependence: Asymmetric responsibilities **(Pilot, Explorer, Explorer)**

Workspace: Table (shared between two Explorers, separate for all others)

Shared Awareness: Sharing feedback on actions and narrated quests

Fig. 3. Outline of the ten sessions, showcasing the physical components used and details regarding groups and their size, Goal, Interdependence, Workspace, and Shared Awareness.

the map was shared by the *MapMaker* and the *Explorer*; finally, in S9 and S10 we had two *Explorers* sharing the same map—one *Explorer* was responsible for the unplugged robot, while the other was responsible for the Ozobot.

3.7 Shared Awareness

We manipulated what and how feedback was given to the children to have different levels of shared awareness during the activities.

3.7.1 Auditory Feedback. Auditory feedback on actions consisted of audio recordings that indicated what the robot was executing (e.g., “the robot is turning left"). When executing the dance action, music would be played. When executing the speak action, a greeting would be played and, if the robot was positioned on the same location as a character (e.g., an animal), a conversation would ensue, progressing the story. Auditory feedback on actions was given to all children in a group (shared) in most sessions—in S2-S4, the audio was played through the Dash robot (and the headphones in S3 and S4); in S5, S6, S9, and S10, the audio was played through the speaker. There was no auditory feedback on actions in S7 and S8, with the group relying on the Explorer to perceive the progress and state of the robot on the map.

3.7.2 Narrated Quests. As mentioned before, the challenges included in the activity were introduced with narrated excerpts of a story. In most sessions, these excerpts were presented to all children in the group (shared)—in S2, one researcher narrated the story; in S5, S6, S9, and S10, recordings were played through the speaker; in S7 and S8, it was the *MapMaker* providing the quests to the other children. In S3 and S4, the narrated quests were not shared, being exclusively transmitted to the *Captain* through the headphones.

3.8 Procedure

Each session lasted approximately 60 minutes and was both video and audio recorded. We divided children into groups depending on the activities, usually, with two or three groups per session. Two to six researchers attended each session and assumed various roles throughout the sessions. At the start of each session, they introduced the activity and its elements to the children. During the sessions, the researchers scaffolded children's participation, mediating interactions within the group, which could involve repeating instructions or even providing physical help with the elements of the activity.

One researcher interviewed children individually during the final session (10 min) and focused on their preferences, asking questions about the overall experience after the ten sessions and the different elements used in the activities. The group interview with the IETs (45 min) was conducted via a videoconferencing platform by another researcher, and centered on three topics: 1) the evolution of the activities and perspectives regarding the different elements used, 2) their perceptions of motivation, engagement, and learning outcomes on the children's part, and 3) their view on how the collaborative activities could be integrated in the school practices.

3.9 Data analysis

Video recordings from the sessions were subject to a thematic analysis. Two researchers (who participated in the sessions) led this analysis, following the method outlined by Braun and Clarke as codebook thematic analysis [5]. After familiarizing ourselves with the videos, we started a structured coding procedure, mixing inductive and deductive, and semantic and latent coding. The initial codebook drew upon previous work, centered on collaboration and awareness [23, 42], child-researcher/teacher interaction [43], and communication strategies [1]. After coding a subset of videos in parallel, we created an initial codebook. Through additional coding and multiple meetings, these researchers refined it by adapting, merging, and adding codes—eventually agreeing on a final version. Then, each coder proceeded to independently code half of the videos, using shared sheet documents to capture coding instances with timestamps, codes, participants relevant to the instance, and notes. The interviews were transcribed and also subjected to coding. To ensure reliability and sprout discussion, coders reviewed each other's coding, taking additional notes and marking disagreements, and then met to discuss and resolve these. After the coding, they met to identify trends and patterns across the data, reaching an outline of themes. The team met to discuss and finalize the themes which we present below. Data collected through observation and note-taking during the sessions and exchanges with the teachers also informed the final themes.

4 Findings

We present our themes, detailing how these varied across specific sessions and providing examples of occurrences observed in the videos. We cover both positive (e.g., working together) and negative (e.g., unbalanced participation) outcomes of the programming activities, and detail what and how specific design decisions elicited or shaped these.

4.1 Working together by fulfilling their roles

Having interdependent roles (S3-S10) was successful in promoting collaboration between children. Each role carried responsibilities and information essential for the progress and success of the shared task at hand, which fostered communication and direct interactions within the group. During the interview, teachers confirmed that these roles were valuable in encouraging collaboration and mutual help. However, it was common for children who were friends to interact more easily. For instance, C6 and C7, who reported being close friends, wanted to work together across sessions. C7 noted in the interview that he felt more engaged when teaming up with C6.

Collaboration usually revolved around the *Explorer* and the *Pilot*, with the first identifying and then transmitting the action (or programming sequence) for the robot to perform, and the second building the corresponding sequence with the coding blocks. This dynamic was successful across all sessions in eliciting collaboration between children.

In S3-S4, the *Pilot* and the *Engineer* had to build the sequence of actions together, with each role responsible for a set of coding blocks. The fact they had to share a workspace and coding blocks fostered negotiation and communication while building the necessary sequence to move the robot. Sometimes, the children playing these roles would simply put the blocks to build the sequence without exchanging words. In other cases, they communicated to reach a consensus, like asking the partner to include one of their blocks in the sequence: "Left, forward, right... [realizing that the play block was missing] put the play on!" (C2 to C3).

Also in S3-S4, the goals of the activity were conveyed exclusively to the *Captain*, through the headphones. This served as a vehicle for children playing it to take on a leadership role, particularly by transmitting the next goal or the progress of the story. For example, C1 was an enthusiastic *Captain*, directing teammates to execute their responsibilities: "*Pilot, Engineer, hurry up!*" (C1 to C2 and C3).

As part of the interaction, children (especially C1 and C2) took the opportunity to engage in role-play. For instance, C1 in S3, after listening to the quest emphasizes the seriousness of it: "*This is very serious*"). They would also call their colleagues by the roles they were playing: "*Thank you, Mr. Pilot*" (C1 in S3); "*Captain, then say, when we reach the end, that it's time to dance*" (C2 in S3). This augmented the interaction between children (and between children and researchers, with researchers following and engaging in role-play) and helped children gain awareness of the different roles and their corresponding tasks.

In all sessions, the group was physically close to each other (more or less depending on their role). Proximity led to children physically helping each other ($M = 2.2, SD = 3.3$)[2]. For example, in S5-S10, the Pilot and the Explorer were sitting side-by-side with the smaller map, which led to them helping one another in assessing the next steps for the robot or identifying the correct coding blocks. In S10, one child joined as a second *Pilot*, sharing the workspace and working side-by-side, which led to more helping instances ($N = 5$), for example, C6 identifying the necessary blocks and placing the new ones while C7 removed the blocks that did not belong in the sequence.

However, roles required interdependence, and their physical distance also led to moments of conflict and intrusion ($M = 17, SD = 7.6$ in S6, $M = 7.8, SD = 7.3$ in all other sessions). This was evident when the roles implied sharing blocks to construct the sequence (S3-S4) or when the workspaces were nearby. For example, in S9, C8 as the *Explorer* was close enough to C9's workspace and added the blocks to the sequence before pressing play.

In S3-S4, the *Explorer* was sitting on the floor apart from the group, while the *Pilot* and *Engineer* sat with their backs to the map on the floor. The children in the *Explorer* role tended to announce the sequence of actions to be programmed loudly and sometimes to approach the table to communicate with the group.

4.2 Little investment in the shared goal

While children had to work together, they generally concentrated on their individual tasks, with little awareness or excitement for the collective progress and for achieving the objectives as a team. This pattern was evident across all sessions. First, children communicated without directly

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[2] M refers to the average coding frequency per group and session

addressing their colleagues. Even though the *Explorer* had to communicate directions to the *Pilot*, they tended to convey these to the researchers/educators. Second, at various moments children acted unproductively ($M = 2.6, SD = 3.6$) to progress in the activity, knowingly or unknowingly disrupting the flow of the activity for their colleagues (e.g., C2 and C3 as *Pilot* and *Engineer* commanding the robot to dance for fun, confusing C4 as *Explorer*). Third, some children easily became distracted or disengaged when they had to wait for their "turn" ($M = 3.7, SD = 3.4$), sometimes diverting their attention to the objects around ($M = 3, SD = 2.9$). During the interview, T3 highlighted: "*Many [children] wanted to play with LEGOs and, at times, they forgot the objective itself*".

Finally, there were scarce moments across all sessions when children expressed enthusiasm or celebrated avidly when achieving an objective ($M = 1.3, SD = 2.5$), these were the most expressive demonstrations of investment/engagement in the shared goal, sometimes with the whole team cheering and clapping (e.g., C1 in S9 yelling "*We are champions!*"). The celebration was usually elicited by sound effects that marked an objective being accomplished and/or by researchers and educators (e.g., clapping, high-fiving). In some sessions, having two teams close by also led to increased excitement as children heard the progress of the other team: "*[A sound effect indicates that the other team found the key] "They already got it right!*" (C9 in S9). In some instances, it seemed to spark some competition between teams: "*[To a child in the other team] We too already found the door!*" (C4 in S3).

In the interview, educators also recognized the recurrent lack of investment in the collective goal. While in most sessions there were challenges of escalated difficulty, during the interview, educators suggested having explicit "*game levels*" for creating enthusiasm around completing the challenges and passing to the next ones: "*Maybe game levels, for example the first level was a smaller circuit and they had to finish it in a certain time*" (T3); "*And having levels, they would also be excited to try to move on to the next level, right? I think it can also help to enthuse them*" (T2).

In later sessions, we added the *MapMaker* role and rewards in an attempt to change how children perceived the goals of the activity. However, neither approach succeeded (detailed below), highlighting the difficulty of promoting shared goals in collaborative learning.

4.2.1 Mapmaker role. In S1-S6, some children showed a willingness to create their own challenges (e.g., deciding where the objectives and obstacles should be positioned). This inspired the introduction of the *MapMaker* role in S7-S8, responsible for determining the goal of the activity. We expected this change to foster more willingness to complete the challenges as a team. However, in these sessions, children did not express much interest in the role. When assuming the *MapMaker* role, rather than constructing a map to support a challenge, they tended to build it for fun and stack LEGO blocks to build tall towers. Researchers had to intervene in every group to ensure there was a map and a challenge for the activity to progress.

4.2.2 Open-ended goal with rewards. As mentioned before, there was enthusiasm around the rewards. However, this approach mostly failed in its intent of emphasizing the shared goal (i.e. acquiring a new sound effect for the robot or an object to customize it). In this session, we observed that children kept mostly focused on completing their individual tasks and were not invested in accomplishing the objectives. Children were undecided about which objectives they wanted to pursue (given that the challenge in this session was designed as a sandbox, providing choice to children where they wanted to go) and sought help from researchers and educators to decide.

4.3 Unbalanced participation and mixed-ability interaction

Having interdependent roles also meant children had to rely on their colleagues to progress. For some teams, collaboration progressed fluently from the start to the end of the session, i.e., without any intervention from educators or researchers. However, children had a wide range of ages and cognitive levels, which resulted in different needs when it came to assessing and acting on their asymmetric responsibilities, often leading to instances of unbalanced participation. For instance, while C2 demonstrated rapid and autonomous problem-solving playing any role, C5 needed constant help from researchers and educators to participate.

At moments when one child was struggling with one task, the progress was congested for the whole group ($M = 3.6, SD = 3.5$). Especially for sessions with larger groups (S3-S4), the waiting times for each child were larger, and oftentimes children would disengage and divert their attention to other activities ($M = 3, SD = 2.9$), for example, building with LEGO blocks while waiting for others. This situation was also highlighted by the teachers in the final interview: "*I think the larger the groups (...) the more they had to wait for the others to play*"- T2). While recognizing this as an issue, T2 pointed out how it can help children internalize the turn-taking: "*They learn to wait*". T2 also suggested that the activity could offer other tasks to complete while waiting: "*Active waiting, they have to be, for example, doing something too, when they wait*".

Unbalanced participation across all sessions led to negative interactions such as children invading their colleagues' workspace ($M = 4.4, SD = 3.5$) and trying to solve the challenge. For instance, in S5, C2 as the Explorer was tired of waiting and assumed both roles claiming that his partner (C4 as the Pilot) "*didn't know* [how to complete her task]".

Another common factor was the children's different visual abilities. Children with residual vision had one more channel to perceive the state of the activity and act faster on it. Children with mild low vision as *Pilot* would often look at the map to find on their own what instructions they should give to the robot, bypassing the need for the *Explorer*. Again, these children expressed frustration about waiting when they could do the activity independently.

Private audio instructions worked to create interdependence between the *Captain* and every other role while ensuring there was a more balanced participation regardless of visual ability—even when children with residual vision were inserted in a team, they did not have all the information and could not figure out and complete the task on their own. Still, children as the *Captain* had to wait until the rest of the team reached a new objective (to receive and transmit a new private instruction). Whenever the rest of the group struggled to reach an objective, meaning that the *Captain* had to pass long periods not actively participating.

4.4 Engagement around novelty and storytelling

We observed instances across all sessions where children expressed boredom and indifference ($M = 3, SD = 2.5$), for instance, sighing, laying their heads on the table, wanting to switch roles, and even asking to stop the activity earlier. Their interest reduced as each activity got closer to the end (mainly due to fatigue) and children who were present in more sessions visibly lost enthusiasm in later sessions—in some sessions, some children were merely playing with LEGO blocks. As detailed above, unbalanced participation also significantly contributed to children becoming disengaged, as they had to wait for their colleagues.

While engagement fluctuated throughout each session and for each child, some elements succeed regularly at gaining or regaining their interest. Across all sessions, there was an appreciation for the sound effects (e.g., indicating success when reaching an objective, music when using the dancing block) and the tangible elements (especially the animal models used to mark objectives). Yet, engagement and enthusiasm were usually centered around novelty and storytelling elements.

4.4.1 Novelty. The introduction of novel elements throughout the sessions led to initial enthusiasm by the children and contributed to their engagement during the activity. These included new action blocks (e.g., loop block introduced in S9), new modes of interaction (e.g., unplugged robot), and other elements (e.g., customization rewards in S10). For example, in S10, children visibly expressed enthusiasm by clapping, asking to hear all possible reward sounds, then laughing and placing the star (reward) on their forehead. The challenges proposed would also increase in difficulty as each session progressed (e.g., starting with step-by-step instructions and then having to build a complete sequence). Yet, there was a degree of repetition—the core tasks for every session remained the same, programming the robot to navigate the map—that led to a lack of enthusiasm to complete later challenges. In the interview, T1 emphasized how children get easily disengaged when an activity is repetitive: "*The moment when it stops being new, stops being a challenge, they know what they're going to do, then it ends up not being as stimulating for them*".

4.4.2 Storytelling and shared awareness. Playing bits of storytelling to introduce the objectives was very efficient in getting children excited to achieve them—these moments usually made the whole group focus on the story, in silence, and on the next quest at hand. Most children were interested in the stories being told (e.g., asking questions about the "invisible robot") and, in many cases, played a part in the story (e.g., talking to the robot, creating new stories).

In S3-S4, these storytelling bits were conveyed exclusively to the *Captain*. There was expressive enthusiasm around this role, with children playing as the *Captain* eager to receive new storytelling bits and visibly excited when transmitting them. During these sessions, some children (C1, C3, and C6) asked repeatedly to switch roles so they could be the *Captain* ("*I want to use the headphones*"). A big part of the engagement was constrained in this role, and we changed this to make narrated quests shared among the team in subsequent sessions.

4.5 Learning, autonomy, and ease of use

All children were able to understand the proposed CT challenges and participate with some degree of autonomy during the activities (as explained before, C5 had significantly more difficulties). As the *Pilot* and *Engineer*, children were able to build sequences of instructions (algorithms), practiced their orientation skills while identifying the correct directional blocks, and some children also learned to apply repetition (e.g., using the loop block to move forward twice). As *Explorers*, they applied data collection while exploring the map, and practiced orientation and perspective-taking conceptualization by identifying the paths the robot should take.

However, children required an active intervention from researchers or educators in all sessions. These helped by supporting children's thought processes ($M = 2.7, SD = 2.3$) or physically finding or reaching an object ($M = 7.4, SD = 6.3$). Researchers regularly asked *Pilots* and *Engineers* to review the sequence of instructions and *Explorers* to repeat the actions they wanted the robot to execute ($M = 6, SD = 5.7$). This way, children had to double-check what they were doing—sometimes finding they made a mistake (debugging). Rarely, did researchers and educators explicitly point out that someone made a mistake and/or gave the solution ($M = 1.6, SD = 2$), except when children were visibly frustrated.

Most of the children's mistakes were associated with their orientation skills (e.g., distinguishing left from right) and perspective-taking. *Explorers* would often rotate their bodies or the (LEGO-based) map to align with the direction the robot was facing to orient themselves (sometimes encouraged by researchers).

Some mistakes also arose due to doubts about using the blocks and their function. In particular, children were sometimes unsure how the blocks should be placed on the LEGO baseplate (e.g., horizontally or vertically, from top to bottom or vice versa). In their first sessions, most children also expressed uncertainty in whether the robot moved relatively to them or to the robot itself (e.g., "my left" versus "the robot's left"). Finally, the actual movement triggered by the left and right blocks also gave space to doubts (e.g., if the robot rotates or slides in the indicated direction; if the robot moves after rotating).

Due to difficulties with orientation and doubts during use, moments of total autonomy were rare. Educators pointed out that researchers' role as mediators was essential for the activity to progress: "*Some difficulties always arise, they need help from someone to explain how to overcome them, because otherwise, they will become unmotivated*" (T2). In moments of frustration, we also observed children simply trying to cheat (e.g., moving the robot to the objective by grabbing it).

4.6 Perception of state and uneven awareness

The different elements within each activity allowed children to be aware of the program, the progress, and the state of the activity. The audio feedback describing the movements of the robot (e.g.,"*I'm turning left*"), its surroundings on the map (e.g., "*The plants in front of me don't let me pass*"), and the sound produced by the wheels allowed blind children to perceive the execution of the program. In S3-S4, where the *Captain* had asymmetric information including feedback on the actions of the robot, they could also provide awareness to the group (e.g.,"*Dash bumped into a wall*" - C1).

Understanding the importance of turn-taking in executing their responsibilities is crucial for the progression and success of the activity. The storytelling and action feedback also played significant roles in guiding children in performing their responsibilities. In S5-S10, where the group shared access to the speaker the whole group was able to perceive the execution and state of the program and react accordingly by deciding on the next steps. In S5, when the robot announced that dancing was the way to pass through the magic plants, C2 was the *Pilot* and promptly placed the dance block in the sequence. The lack of audio feedback was a factor that influenced awareness and was pointed out by children commenting on the lack of wheel sounds when using the unplugged robot (C2 in S5) and the lack of feedback on actions during (C1 in S8).

4.6.1 Perceiving the map. The groups included children with different visual abilities, creating an unbalance in the perception and awareness of the ongoing activity. For children with usable vision, the experience was more immediate and comprehensive, as they could observe the actions of the robot on the map and quickly perceive its new state. In groups where the *Pilot* had usable vision and could see the map from afar, they had an advantage in figuring out the next commands and even debugging the sequence first. In S5, we can observe C7 as the *Pilot* using his residual vision to bypass C1 as the *Explorer* and carrying the activity. Another example of this unbalanced awareness happens when C6 as *Explorer* does not physically explore the map and is quick to give new commands since he is using his residual vision.

In contrast, blind children rely on physically exploring the map to perceive the state of the program, which, in turn, can interfere with the movement of the robot. In S2-S4 with the floor map, blind children with the role of *Explorer* (C1 and C5) would crawl on top of the map to follow the robot, unintentionally displacing map elements such as 3D animals and cardboard walls. In S5-S10 with the LEGO-based map, C11, a blind *Explorer* would easily misalign the movement of the robot when using his hands to follow it on the map. These barriers result in uneven awareness levels within a group with mixed visual abilities, making it more demanding for blind children to comprehend the execution of a sequence or requiring them to repeat the program's execution. Teachers noted during the interview that while it is important to have objects that provide context, these objects should be fixed to allow blind children to explore and build a mental model of the challenge without disrupting the setup and their perception.

4.6.2 Controlling the unplugged robot. The introduction of the unplugged robot aimed at empowering the role of the *Explorer* with more control and awareness, yet it proved to have significant trade-offs regarding orientation and keeping track of the state. With the unplugged robot, we sought to explore how it affected perception and awareness, requiring children to move the LEGO figure and execute the program themselves. Despite the advantages of engagement and immediate awareness, any distractions or indifference resulted in lapses in the awareness of the unplugged robot's positioning, orientation, or even oversight in executing the sequence ($M = 8.8, SD = 7$ in S5-S6, $M = 2.9, SD = 5.2$ in all other sessions). In S6, C8 displayed uncertainty on how to move the unplugged robot, waiting for confirmation from the researcher. Furthermore, children expressed disappointment when they realized there was no actual robot, emphasizing the importance of the tangible, physical presence of the robot (e.g. when asked about his preference in the interview, C1 answered "Yes, because I like the robot more").

5 Discussion

Our findings show how the introduced elements impacted children's collaboration dynamics and overall experience. We now answer the proposed research questions and discuss the implications of our work for designing future inclusive kits for collaborative learning. These center on discussing 1) opportunities to balance interdependence and improve collaboration flow, 2) trade-offs when shaping individual and collective awareness toward equity in mixed-ability school-based contexts, and 3) implications for the design of children-led collaborative learning kits and activities.

5.1 RQ1: How can we enhance collaboration in non-visual computational thinking activities?

During our sessions, we observed a different range of collaborative moments - some were fluid and productive, while in others, children were more focused on individual tasks, disrupting progress, or even disengaging from the activity. While interdependent roles ensured teamwork, it also foregrounded the heterogeneity of the group. In the context of game design, Harris and Hancock [17] have explored asymmetric roles with varying degrees of interdependence, offering valuable insights for collaborative learning. While a tightly coupled interdependence can enhance the overall experience and a greater sense of connectedness [17], these outcomes largely depend on the group and its social context. In our study, the degree of interdependence was not appropriate for all teams, due to differences in ability, cognitive development, and motivation. This mismatch sometimes led to frustration, disengagement, and disruptive behaviors, with some children programming random sequences or altering the map for their own fun. Thus, asymmetric interdependent roles are an effective approach to enhance collaboration when carefully designed to match individual abilities.

Our findings also suggest that integrating "rhythms of interdependence" as suggested by [17]—**periods of varying intensity and direction in collaborative tasks—can alleviate fatigue and maintain engagement, supporting an inclusive experience and foster a sense of individual contribution**. For instance, after reaching a group objective, the Pilot can independently create a music sequence, while the Explorer uses blocks to build paths and bridges on the map before proceeding with the navigation of the robot. Thoughtful design decisions, such as avoiding roles with excessive downtime, can reduce tension in interdependent tasks. In our activities, waiting times (e.g., the Captain waiting for others to finish their roles) sometimes hindered progress. To minimize downtime and further support collaboration, educators suggested incorporating optional side tasks for different roles and keep children productively engaged. The introduction of the MapMaker role—responsible for designing the map layout, setting up the story, and creating challenges—demonstrated the potential of creative tasks to maintain engagement even during waiting periods. Empowering children to make **creative decisions reduced frustration and encouraged a deeper connection to the activity**.

The multimodality of the environment was a focus of children's enthusiasm while providing different opportunities to balance participation and awareness. For example, introducing the *Captain* role with "secret information" promoted more balanced participation by prompting communication between roles, and increasing children's enthusiasm with more control and awareness. In the context of mixed-visual ability robotic activities, Chibaudel et al. [7] have shown the potential of embodied robotic activities in mixed-visual ability contexts. Our unplugged robot aimed at improving the awareness and overall control of the *Explorer* role. However, it accentuated some of the children's difficulties, such as orientation, perspective-taking, and maintaining the state of play. It is also important to recall that children in our study expressed disappointment when there was no physical robot, **emphasizing the significance of a tangible presence for an engaging experience**, in particular for blind children [47].

Effective engagement requires a strong initial explanation, especially to help children understand their roles. The success of pre-recorded narrated quests in introducing challenges suggests that narration could play a vital role in onboarding and mediation. A digital app, similar to a tutoring agent proposed by Singley et al. [44], to support multi-user collaboration and "keep things moving in a productive direction", could introduce rules, maintain the flow of the activity, present new challenges while supporting their progress. Furthermore, children often had doubts regarding the movement of the robot and the positioning of the coding blocks, and such an app could also provide real-time clarifications. This approach would empower children to participate with greater autonomy while keeping the learning process dynamic and engaging.

Finally, the **integration of educators into the learning environment is crucial for collaboration success**. By assigning them asymmetric roles—such as managing rewards or providing assistance—they can facilitate the activity without detracting from the children's autonomy. This aligns with research showing that educators are key to creating a supportive learning environment, especially when resources for new activities are limited [39].

5.2 RQ2: What factors positively influence collaboration in school-based settings?

Several key factors emerged as drivers to foster positive collaboration. As previously mentioned, an asymmetric and interdependent design can enhance collaboration. In previous work, leveraging role-play and exclusive access to information, like asymmetric information, helped balance the interaction promoting social play and collaboration [42, 44]. In our sessions, introducing the *Captain* role with **"secret information" increased children's enthusiasm** by providing them with more control and promoting communication flow between the different roles. Clear communication between children, teachers, and researchers also played a key part in maintaining collaboration, highlighting the importance of shared goals and well-structured tasks.

The integration of **storytelling and thematic tasks emerged as a powerful motivator**. Children responded positively to the narrative elements, indicating that further embedding storytelling into task design could help sustain collective engagement. For instance, incorporating character-driven challenges or unfolding storylines as part of the activities could deepen their involvement and excitement. As seen in previous work [36], blending multisensory elements along with themed narratives fostered awareness and engagement for children with visual impairments providing meaningful experiences for the whole group.

A significant challenge throughout the sessions was sustaining motivation and engagement. While the introduction of new elements and a sandbox activity, including rewards for collective effort, initially excited the children, maintaining their enthusiasm required more than simply adding features. The multimodal environment—featuring sound effects and physical rewards—helped engage the children in their collaborative tasks. However, the repetitive nature of core activities, such as robot navigation, eventually led to waning interest. Drawing inspiration from legacy board games [9], we suggest incorporating **unlockable features and challenges that evolve as children progress**. This would help maintain long-term engagement by offering rewards tied to group achievements. Allowing children to encounter and overcome failure on their own also proved effective in sustaining their participation. Although researchers frequently intervened to prevent frustration, it became apparent that empowering children to troubleshoot and learn from their mistakes independently led to deeper learning outcomes and increased resilience.

5.3 Design Guidelines for Inclusive Collaborative Learning Kits

Based on our findings, we propose the following design guidelines for collaborative learning kits to create more inclusive, engaging, and sustainable learning environments for children of all abilities:

´´Rhythms of Interdependence": Varying the intensity of interdependent collaboration while catering to diverse abilities, ensuring that no role experiences excessive waiting time. Periodic shifts in responsibility can help maintain engagement while waiting for others and promote a sense of personal achievement alongside collective success.

Multimodal Workspace Awareness: Incorporating tangible, audio, and haptic elements can promote shared physical space and support workspace awareness for children with different sensory abilities. Features like haptic feedback, asymmetric audio cues, or 3D-printed components can engage children and enhance their awareness, fostering more closely coupled collaboration.

Narrative and Rewards: Use storytelling and unlockable rewards to maintain motivation. Introducing new challenges, features, or tasks as the group progresses can sustain interest and provide a sense of accomplishment over time.

Educator Involvement: Integrating teachers or educators into the activity by assigning small, asymmetric roles can enhance group dynamics while remaining manageable for them to oversee multiple groups (e.g., within a classroom setting). In our activities, this approach was manageable, and the children enjoyed the involvement of the researchers, who acted as a "control tower," relaying information to each group's *Captain*, or as a "storefront" in the sandbox activity.

Digital Tutor: Tools like a digital app or a "tutoring agent" [46] could support this process by providing real-time feedback, reducing the need for constant intervention, and helping the group remain focused and productive.

6 Limitations

The performance of a prototype can significantly impact user experience. Due to the rapid pace of this exploratory study, the frequent modifications and additions to the computational kit created room for occasional malfunctions and unreliable robot movements. The Wizard of Oz method, while valuable, is susceptible to human error and introduces potential lag between play and execution, thereby disrupting the intended user experience. Furthermore, intricate design elements and fiddly components may present challenges for young users, resulting in frustration and influencing their interaction with the technology.Another limitation we should acknowledge is the time gap between sessions, which can cause fluctuations in engagement and influence children's participation. These prolonged intervals can affect the retention of information and learning, reducing the effectiveness of tasks when compared to more frequent sessions.

While all sessions were video recorded, there were occasions when children moved out or away from the frame, posing challenges to our analysis.

Even though we had a small sample of children, it represents a crucial user group when designing inclusive education technologies and identifying challenges in mixed-ability settings. Lastly, we acknowledge that the school context, familiarity between children, and scaffolding of the activities impacted the children's experience. We attempted to understand how teachers could seamlessly incorporate these activities into their weekly routines (and potential barriers). However, we could not gather much insight regarding this aspect, as teachers' comments on this aspect solely focused on barriers associated with limited resources and time constraints.

7 Conclusion and Future Work

In this 10-session study, children with visual impairments engaged in collaborative activities using a multimodal coding kit. In line with previous work, our exploration reveals the potential of coding kits to promote inclusive collaboration within a CT activity. However, our study highlights the importance of recognizing the diverse range of abilities within groups, which can impact collaboration dynamics and lead to unbalanced participation and awareness. We believe our research contributes valuable insights to refine the design of collaborative coding environments inclusive of children with visual impairments in a school setting.

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