Fostering collaboration with asymmetric roles in accessible programming environments for children with mixed-visual-abilities

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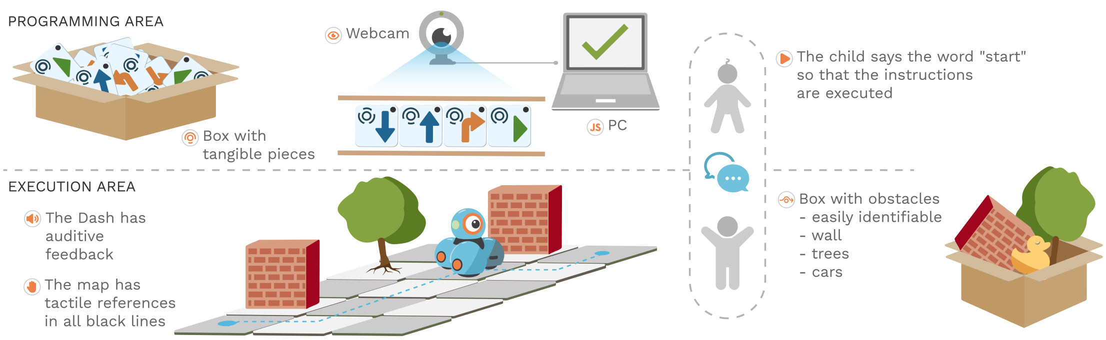

Fig. 1. System overview diagram.

Introduction of computational thinking training in early childhood potentiates cognitive development and better prepares children to live and prosper in a future heavily computational society. Programming environments are now widely adopted in classrooms to teach programming concepts. However, these tools are often reliant on visual interaction, making them inaccessible to children with visual impairments. Also, programming environments in general are usually designed to promote individual experiences, wasting the potential benefits of group collaborative activities. We propose the design of a programming environment that leverages asymmetric roles to foster collaborative computational thinking activities for children with visual impairments, in particular mixed-visual-ability classes. The multimodal system comprises the use of tangible blocks and auditory feedback, while children have to collaborate to program a robot. We conducted a remote online study, collecting valuable feedback on the limitations and opportunities for future work, aiming to potentiate education and social inclusion.

CCS Concepts: • **Human-centered computing** → **Accessibility**.

Additional Key Words and Phrases: visually impaired, children, collaboration, tangible, robot, accessible

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1 INTRODUCTION

Learning computational concepts at a young age allows children to start developing creative and cognitive abilities, abstraction, planning, and problem-solving skills [14]. Nowadays, various programming tools [4, 8] are used to teach computational thinking in early childhood education contexts, prominently block-based environments. These allow children to build code by dragging and connecting blocks, reducing the cognitive load presented in text-based environments [4]. However, most screen-based virtual environments are not accessible to children with visual impairments. Previous work sought to bridge this gap by relying on screen readers [10] and leveraging tangible interaction [6, 7, 9, 11, 14, 16].

The manipulation of tangibles has been shown to reduce cognitive load while simultaneously developing motor, perceptual and cognitive skills [1]. Robots are tangible and engaging to children. Using robots to program spatial activities can reinforce cognitive and spatial abilities [10, 14]. However, most tangible programming environments do not consider accessibility in their design [14]. Physical blocks generally do not have tactile cues for action recognition, orientation, and correct assembly. Torino [11] and StoryBlocks [7] are examples of previous work exploring how to make tangible environments more accessible with audio output.

Collaborative learning engages children to perform tasks to achieve a shared goal. It can foster self-esteem, social skills and learning [3, 13]. Previous work explores tangibles, music, and sound to foster mixed-visual-ability collaboration [9, 13, 16]. These works also highlight the importance of role assignment, as children are required to communicate and collaborate to succeed, and have a positive learning experience where they prove their strengths [3, 12, 13, 16].

2 APPROACH

By acknowledging the benefits of block-based syntax, tangibles and robots, we designed an inclusive programming environment for children with diverse visual abilities. We leveraged asymmetric roles to foster collaboration and communication. The system is composed of a web application, tangible coding blocks, the Dash[1] robot, and a play mat for the robot to move on top [Figure 1].

The app uses the computer's camera to recognize the TopCode[2] markers in the blocks and send the instructions via Bluetooth to the robot. The programming blocks are cardboard squares, with TopCode markers, tactile references for orientation, and arrow-shaped colored reliefs to indicate the direction. There are four movement blocks: forward, backwards, turn 90º left and right. The "start" block completes and activates the sequence to be executed by the robot. Dash is augmented to give audible feedforward and feedback on its actions.

The execution area is composed of a 5×3 checkered mat, with tape to differentiate the squares, and a defined starting position for the robot. In the programming area, the blocks are ordered from left to right, and the "start" block is added to the end of the sequence. A virtual map is generated by the app, with obstacles in some of the squares. However, the play mat is initially empty. The users must collaborate to navigate the map with the robot, mark the position of the obstacles, and find the unobstructed path to the goal. When the robot is about to collide with an obstacle square, it

[1]Dash Robot. Wonder Workshop. https://www.makewonder.com/robots/dash/ (Last visited on June 21st, 2021)
[2]TopCodes: Tangible Object Placement Codes. http://users.eecs.northwestern.edu/~mhorn/topcodes/

stops, and gives feedback. In each step, children should try a sequence of instructions and iteratively discover the map structure. The child in the execution area explores the map, and adds the obstacles as they are discovered. The child in the programming area builds the coding sequences according to the feedback given by the other.

There are two interaction modes, step-by-step and sequential. In the step-by-step game mode, the robot will only execute one instruction at a time and the users have the opportunity to explore the map. In the sequential mode, the users build the full sequence of instructions for the robot to execute. After executing a sequence, the robot will return to the starting position.

3 PRELIMINARY STUDY

We conducted an online study to gather preliminary feedback. Our goal was to identify advantages and limitations, confronting the approach and the design with the knowledge and experience of experts in the context where the system is to be deployed (i.e., in school, at home). We contacted schools with a leading role in the education of blind and low vision minors in our country [15], parents' associations, and researchers working in the field. We recruited sixteen participants, twelve special needs educators (SNE1-SNE12), two parents (P1-P2), one researcher (R1), and one person employed in a reference institution for the rehabilitation and integration of visually impaired people (E1). Eight participants (SNE1, SNE3, SNE7, SNE10, SNE11, SNE12, R1, and P1) had experience with robots, yet only one (SNE12) was familiar with the Dash robot. We sent an online questionnaire to participants with an embedded video introducing the system, the components, and the interaction modes. The video is available in Portuguese[3]. We collected participants' perceptions on the system, how it can be an inclusive programming tool fostering collaboration. Answers were subject to an inductive thematic analysis [2] by two of the researchers.

3.1 Results

Participants found the overall system and its elements attractive, easy to manipulate and to comprehend. Educators mentioned the coding blocks were an advantage and suited the system, as they are "*a valid alternative to recognize the instruction*" (SNE5), and "*easy to handle [...] understand and use*" (R1). The robot, its color, shape, and audio feedback was also considered appropriate. However, some educators were worried the interaction could be restrained, due to some aspects presented. SNE5 suggested the robot should have tactile cues, so children are able to identify its front side. E1 argued that the tactile exploration of the play mat did not seem practical for children with visual impairments — suggesting the use of solid three-dimensional obstacles (instead of the prototype cardboard presented) and descriptive audio cues to convey movement and collision with obstacles. SNE1 also showed concerns, as some of her blind students felt uncomfortable using robots: "*a certain fear even [...] as they do not control the object and feel strange to hear an object speaking and moving*". Six participants suggested the obstacles should relate to children's daily life: "*animals, houses [...] Any obstacle that you may encounter on the street or at home*" (SNE1).

Learning & Skill development. Educators recognized the potential of the system to train computational thinking skills in early childhood: "*the introduction to programming concepts is excellent*" (SNE3). They also underlined the benefits of the system in training spatial reasoning, orientation, and mobility: "*the stimulation of spatial concepts and laterality, orientation*" (SNE6). Likewise, participants also highlighted the development of cognitive reasoning, such as problem-solving and planning abilities: "*cognitive development through play*" (SNE9); "*it may allow amplifying their vocabulary and mental dexterity*" (SNE4). Educators believe that if the system is to be used in schools, it could be an

[3] https://youtu.be/hdoPCq8b88g

advantage to learn other school subjects in this context, — "*basic math subjects like rotation degrees or units of measure*"; "*in geography and math as a means to work the cartesian coordinates*" — or even for children with visual impairments to train real-life paths — "*paths could be trained, such as home, or school, or even an outdoor course*" (SNE5). SNE8 suggested the activity could be integrated with trivia or questions related to subjects taught in class.

Fostering interaction and inclusion. Participants referred to the importance of having different tasks and the possibility to exchange roles: "*encourages team work, interaction and cooperation in learning*" (SNE8). It was also suggested the activity could be played by competing teams of two, or teams of more players, "*as long as they have different tasks*" (SNE8). The activity was depicted as a catalyst for socialization and inclusion among mixed-ability classes: "*communication and socialization facilitator*" (SNE9); "*in the classroom, it can be an asset in strengthening interpersonal relationships and the spirit of mutual help*" (SNE7). Some educators also speculated this could be reflected in family contexts "*in the family context, it can promote cohesion and develop autonomy*" (SNE7); "*strengthen family ties and interaction between siblings* (SNE3).

Complexity & Challenge. Regarding the existing game modes, educators considered the two complemented each other. SNE1 mentioned how the step-by-step mode "*introduces the programming concepts*" and is "*more directed to an age group of younger students*" and how the sequential mode "*introduces sequences, perfect for third and fourth grade students*". Some suggested ideas on how to make the challenge more elaborate and captivating. Regarding the actions provided, participants mentioned they should include other computational concepts, namely repetition and conditionals. SNE6 stated that increasing the number of squares on the play mat "*would allow for more complex problem-solving and more stimulating challenges*" and even suggested the addition of upper and lower floors, "*training one more dimension*". Similarly, SNE12 suggested the task of managing the play mat could imply the use of three-dimensional objects to build bridges and ramps for the robot to go up and down between different floors.

4 OUTLOOK

Participants found the system attractive, and with potential for children to learn basic programming concepts. They recognized its potential in training spatial reasoning, laterality, orientation and mobility. However, it was mentioned the system was presently oversimplistic. Participants suggested to include more explicit tactile and auditory cues for better exploration and action recognition. Educators also considered the activity could cater for different age ranges, if different levels of difficulty were designed. In particular, increasing the number of squares on the play mat and the use of three-dimensional objects to build structures for the robot to interact were suggested as design options to enhance the challenge, engagement and interaction. We also found the opportunity to integrate the approach in the context of other school subjects to reinforce learning. For children with visual impairments, in particular, to train real-life paths.

Participants highlighted the importance of having different tasks throughout the activity to encourage interaction. The use of the system both at school and home was pictured as beneficial for promoting interpersonal relationships and socialization with others. By assigning different roles and asymmetric information to each child, the activity imposes constant communication and collaboration. Likewise, asymmetry was shown before to increase the feeling of connectedness and social presence in collaborative digital games [5]. In our approach, map exploration and ensuing detection of obstacles are designed to channel the interchange between roles and tasks. The empty map with 'invisible' obstacles at the start is a purposeful design option, aiming to challenge both children with and without visual impairments, and balance the collaboration between them. Despite this, participants highlighted potential barriers to mixed-ability interactions. Future work should ensure the elements on the play mat are easily perceived and handled, and the system is able to give explicit feedback according to robot's movement and collision with obstacles.

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